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# Microwave Landing System Autoland System Analysis

J. B. Feather  
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McDonnell Douglas Corporation  
Douglas Aircraft Company  
Long Beach, California

December 1991

Prepared for  
NASA-Langley Research Center  
Under Contract NAS1-18028



National Aeronautics and  
Space Administration



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## **ACKNOWLEDGEMENT**

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### **MD-80 Program:**

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### **Flight Operations:**

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## GLOSSARY

AC	Advisory Circular
AFCS	Automatic Flight Control System
AGL	Above Ground Level
DFGS	Digital Flight Guidance System
DG	Directional Gyro
DME/P	Precision Distance Measuring Equipment
EFIS	Electronic Flight Instrument System
FAF	Final Approach Fix
FMA	Flight Mode Annunciator
FMS	Flight Management System
GPS	Global Positioning System
GS CAP	Glide Slope Capture
GS TRK	Glide Slope Track
ILS	Instrument Landing System
INS	Inertial Navigation System
IRS	Inertial Reference System
IRU	Inertial Reference Unit
LOC CAP	Localizer Capture
LOC TRK	Localizer Track
MLS	Microwave Landing System
MLW	Maximum Landing Weight
ND	Navigation Display
PFD	Primary Flight Display
VE	Equivalent Airspeed
VG	Ground Speed



## **SECTION 1**

### **EXECUTIVE SUMMARY**

The objective of this study is to investigate the ability of present-day aircraft equipped with automatic flight control systems to fly advanced MLS approaches that are being proposed as future operational procedures. The technical approach used to achieve this objective included reviewing the design and autoland operations of MD-80 series aircraft, simulating several MLS approaches using a batch simulation program with the present-day MD-80 as the baseline study model, and having Douglas Flight Operations review and comment on the proposed procedures.

As a result of the simulation, several changes to existing procedures would have to be made in order to successfully fly the curved path approaches. The rules and procedures for straight-in ILS paths will need to be modified to accommodate the new curved paths that can be flown using MLS. No significant changes to procedures for the vertical profile were identified since the MLS vertical descents are very similar to present ILS glide slope procedures.

In some cases, the simulation results indicated changes to the existing flight hardware and/or software would be necessary. The cases so identified involved changes to the localizer system inner loops (such as gains, event times, and switching logic). Most of these cases featured short final segments where low altitudes (approximately 450 feet) prevented establishment of normal localizer capture and track modes.

A review of flight operations by Douglas engineering pilots highlighted the requirement for procedural changes when flying new MLS paths. In addition, it was noted that a pilot flying MLS approaches must have adequate information displayed to give him confidence in the MLS equipment, procedures, and capabilities.



## SECTION 2 CONCLUSIONS/RECOMMENDATIONS

### 2.1 CONCLUSIONS

Simulated MLS curved path autoland approach procedures as performed in this study are not compatible with the present day MD-80 aircraft avionics capability, autoland certification, and in particular, flight crew operating procedures. ILS look alike approaches (using MLS-generated path deviations) are the exception, due to the fact that they emulate existing ILS operations and performance. These conclusions are derived from simulation data results and analysis, as well as MD-80 flight crew feedback.

However, with the modification of the current MD-80 flight crew operational procedures, as well as aircraft flight displays, several MLS curved path approaches attempted in this study are possible. These modifications consist of revising present day flight crew procedures in order to instill crew confidence in the aircraft's system status, position relative to the runway, and performance throughout the entire MLS curved path approach procedure. In addition, aircraft attitude, as well as mapping (position) displays would need to be enhanced in order to provide more precise position information to the flight crew.

Finally, if the current MD-80 avionics system is used unmodified, several approaches are not feasible, regardless of crew procedures. In addition, DFGC changes would be required to provide acceptable lateral touchdown velocities based on passenger comfort considerations. In order to allow MLS curved path autoland approaches which feature turns to the final straight segment at low altitudes (below about 450 ft AGL) close to the runway threshold, the current Digital Flight Guidance Computer (DFGC) would require modifications.

### 2.2 RECOMMENDATIONS

In order to allow MLS curved path approaches and subsequent autolands to be successfully completed with the present day MD-80 avionics hardware/software, flight crew procedures need to be redefined. Extensive pilot training in MLS operations, both from an avionics hardware standpoint, as well as for aircraft dynamics, would be required. This task would ensure that flight crews have a thorough knowledge of MLS procedures in order to correlate these new operations with that of the present day ILS. As a result, crews would encounter localizer captures lower than the current accepted minimum altitude of approximately 1,500 ft with confidence in the aircraft performance during the curved path-final straight segment transition, as well as position relative to the runway throughout the entire approach procedure.

In order to perform MLS curved path approaches which dictate autoland criteria completion below 300 ft, DFGC localizer control law revisions would also be required. These revisions might consist of enabling the capture and tracking of the curved path ground track, instead of waiting to capture and track the approaching localizer. This revision would enable control law stabilization at a significantly earlier stage in the approach, preventing possible localizer overshoots, and providing accurate tracking of the approach path to touchdown.

#### 2.2.1 Follow-On Studies

Upon identifying several limitations encountered in the performance of the MD-80 aircraft in MLS curved path autoland approaches, the following follow-on studies are recommended:

1. Establish flight crew procedures (including system failure management) which can be utilized to perform MLS curved path autoland approaches with the existing DFGC autoland hardware/software.
2. Redefine DFGC control laws in order to accommodate capture, and subsequent tracking of the MLS curved path elevation and azimuth throughout the entire approach via autoland guidance.
3. Investigate the modification of existing DFGC autoland software criteria in order to allow initial autoland engagement at altitudes below 300 feet.
4. Investigate DFGC hardware/software changes required to perform MLS curved path departures.
5. Upon realizing a design architecture for a digital avionics system capable of performing MLS approaches and departures, perform a hazard analysis in order to identify functional hazards which might inhibit safe operations in this configuration.
6. Establish generic FAA certification requirements for MLS operations.



## **SECTION 3**

### **STUDY AIRCRAFT DEFINITION**

This study incorporates a technical model of the DC-9 series 80 (MD-80) twinjet aircraft. The MD-80 is a medium range aircraft which is currently flown in several different configurations: MD-80, 81, 82, 83, 87, and 88. Of these configurations listed, only the MD-87 differs in actual aircraft size with a fuselage length shortened by approximately sixteen feet. The remaining configurations differ in certified gross weight, range, engine selection, as well as avionics equipment.

#### **3.1 DIGITAL FLIGHT GUIDANCE SYSTEM (DFGS)**

This study will focus on the MD-80 longbody aircraft incorporating two Digital Flight Guidance Computers which provide the following functions:

- Autopilot
- Flight Director
- Speed Control
- Autothrottle
- Mach Trim Compensation
- Yaw Damper
- Thrust Rating
- Selected Thrust Cutback
- EPR Synchronization
- Automatic Reserve Thrust
- Altitude Alert/Preselect
- Fail-Passive Autoland

#### **3.2 AUTOLAND DEFINITION**

The MD-80/87 series aircraft are certified to perform a fail passive autoland to CAT IIIA minimums (700 ft RVR, 50 ft DH) meeting requirements established by AC 120.28B, and AC 20-57A.

##### **3.2.1 Autoland ILS Sequence**

The autoland sequence is initiated at an altitude of 1,500 feet and is subject to valid sensor inputs. Included as required inputs are the dual normal and lateral accelerometers, 2 valid vertical gyros, 2 valid flap positions greater than or equal to 26° (landing configuration), full authority rudder servo engaged and valid, 2 agreeing course (runway heading) and heading inputs, 2 radio altimeters indicating valid below 1,500 feet, as well as 2 valid ILS receivers.

The autoland sequence consists of capture and subsequent tracking of the ILS beam during which bank angles of  $28 \pm 2^\circ$  are available to capture the localizer. Bank angles are limited to  $10 \pm 1^\circ$  down to 200 ft when tracking localizer; thereafter they are limited to  $5 \pm 1^\circ$ . Full authority ( $\pm 22^\circ$ ) parallel rudder engagement ensures full rudder travel is available to the autopilot for control in crosswinds and possible engine out conditions.

Glide slope capture is initiated as the aircraft intercepts the beam center, with capture performance varying with the aircraft airspeed/closure rate. Localizer capture should be obtained prior to glide slope capture for best results.

At a radio altitude of 150 ft, the align mode is engaged. During this mode, any crab used to maintain the localizer beam center is removed and a forward slide slip is initiated. Runway heading is established using rudder control with the aircraft lateral position continuously guided by the localizer beam center using aileron control in the side slip.

At approximately 50 ft, varying with aircraft sink rate, the flare mode is initiated during which the aircraft pitch axis is controlled in order to reduce sink rate to a level appropriate for touchdown. During this phase, glide slope tracking is terminated.

Finally, following main gear compression and wheel spinup, aircraft nose lowering is initiated. The autoland sequence is terminated five seconds after nose gear strut compression. A rollout option is available to customers which allows runway localizer tracking following touchdown.

### **3.2.2 System Limitations**

Inclusive in the autoland certification are the following Digital Flight Guidance System limitations:

The autoland is limited to the maximum wind conditions of:

Maximum Crosswind . . . . . 15 knots

Maximum Headwind . . . . . 25 knots

Maximum Tailwind . . . . . 10 knots

The following control law limits are used by the DFGC:

Maximum Bank Angle . . . . .  $28 \pm 2^\circ$  (Localizer Capture, LOC CAP),  
 $10 \pm 1^\circ$  (Localizer Tracking, LOC TRK),  $5 \pm 1^\circ$  (< 200 ft)

Maximum Intercept Angle . . . .  $90^\circ$  (Intercept angles >  $90^\circ$  may offer less than optimum performance)

Maximum Roll Rate . . . . .  $5 \pm 1^\circ/\text{sec}$

### **3.2.3 Flight Mode Annunciation**

Two Flight Mode Annunciators (FMA) are installed in the aircraft; one on the Captain's instrument panel, and one on the first officer's instrument panel. Each FMA displays the current DFCS throttle, armed, roll, and pitch modes, and provides the flight crew a means of monitoring the autoland sequence throughout the approach. (See Figure 1.)

### **3.2.4 Minimum Equipment List**

The following minimum equipment is required in order to perform autolands as demonstrated to the FAA:

<u>QUANTITY</u>	<u>SYSTEM</u>
1	Digital Flight Guidance Computer
1	Autopilot
2	ILS Receiver
2 or 1	Radio Altimeter (1 w/Collins 552A Radio Altimeter) (Note: 2 required for CAT IIIA weather minima)
2	Radio Altimeter Indicator
2	Attitude Sensor (VG/AHRS/IRS)
1	Central Aural Warning System
1	Warning Annunciator
1	Flight Mode Annunciator
1	Decision Height Light
4 or 3	EFIS Display (EFIS Equipped Aircraft) (3 w/Pilot Flying PFD in Compact Mode and ND in ARC or Rose Mode)
1	Automatic Ground Spoilers
2 or 1	Engines (Autoland May Be Completed w/One Engine if Failure Occurs Below 50 ft)

SPD 155	LN3 ALT	XDS SEL	VERT SPD	AIRPLANE DESCENDING ON INTERCEPT HEADING FOR LOCALIZER — AUTOLAND AND ALTITUDE PRESELECT ARMED
SPD 155	LN3 LOC	LOC CAP	ALT CAP	LOCALIZER AND ALTITUDE CAPTURE INITIATED — TURNING UNTO LOCALIZER AND LEVELING OUT ON APPROACH ALTITUDE
SPD 155	LN3 LOC	LOC TRK	ALT HL3	LOCALIZER AND ALTITUDE CAPTURE COMPLETE AIRPLANE TRACKING LOCALIZER — ARMED FOR GLIDESLOPE INTERCEPT
SPD 155	LN3 LOC	LOC TRK	GLS CAP	GLIDESLOPE CAPTURE INITIATED
SPD 135	LN3 LOC	LOC TRK	GLS TRK	CAPTURE COMPLETE LANDING FLAPS AND APPROACH SPEED SELECTED — PARALLEL RUDDER ENGAGED
SPD 135	LOC CAP	LOC TRK	ALT LN3	AUTO GO-AROUND LOGIC SATISFIED AND AUTOMATICALLY ARMED DUAL AUTOLAND LOGIC SATISFIED
SPD 135	LOC CAP	LOC TRK	ALT LN3	ALIGN MODE INITIATED AT 150 FEET — TRANSITION FROM CRAB ANGLE TO FORWARD SLIP MANEUVER BEGINS
RET 0	LOC CAP	LOC TRK	ALT FLARE	AUTOTHROTTLE RETARD AND AUTOPILOT FLARE AUTOMATICALLY INITIATED AT APPROXIMATELY 50 FEET
RET 0	LOC CAP	LOC TRK	ALT FLARE	AT MAIN GEAR SPIN-UP, ROLLOUT BEGINS — NOSE LOWERING INITIATED AUTO GO-AROUND REVERTS TO FLIGHT DIRECTOR GO-AROUND WITH ROLLOUT OPTION; LOCALIZER RUNWAY TRACK MAINTAINED WITH RUDDER AND NOSEWHEEL STEERING
RET 0	LOC CAP	LOC TRK	ALT FLARE	WITHOUT ROLLOUT OPTION, AUTOPILOT DISENGAGES 4 SECONDS AFTER NOSEWHEEL COMPRESSION

FIGURE 1. FLIGHT MODE ANNUNCIATION SEQUENCE

## **SECTION 4 SIMULATION DEFINITION**

### **4.1 MD-80 STUDY MODEL**

A six degrees of freedom, large flight envelope simulation program of the MD-80 aircraft was used as the study model. (See Figure 2A.) This basic program has been used in the past for various MLS studies (Reference 1 and 2). A block diagram showing the ILS/MLS switching mechanism is shown in Figure 2(B). The MLS pitch and roll commands are input to the inner loops instead of the conventional ILS commands. The major change for this study has been the transition from MLS curved path guidance to that of an autoland approach. The simulation includes an autoland capability that is armed when the aircraft is established on the final straight portion of the approach. With all autoland criteria having been satisfied, the simulated autoland approach will continue to touchdown. Data during this final approach and at touchdown are recorded. Section 6 presents and discusses this data.

### **4.2 DFGS IMPLEMENTATION**

The Digital Flight Guidance Computer (DFGC) is the heart of the MD-80 fail passive autoland system. The DFGC receives data relative to aircraft position, velocity, acceleration, command references, system discretes, and servo monitors. The DFGC uses this data to compute attitude as well as rate commands for aircraft stabilization and control.

In order to implement the DFGC in simulation, a baseline DFGS has been defined which is capable of simulating the flight guidance functions over the entire flight envelope, in various environmental conditions, modeling the aerodynamic characteristics of the MD-80 aircraft. These characteristics are modeled using small perturbation equations of motion.

The autothrottle, pitch, roll, and yaw control laws, complementary filters, as well as pitch and yaw compensation systems (mach trim and yaw damper) are modeled for the DFGS simulation. In addition, mechanical flight control systems such as the throttles, servos, actuators, and cables are interfaced with the DFGS simulation. Finally, sensors providing engine, radio altimeter, ILS, air data, angle of attack, acceleration, attitude, as well as surface position information are modeled.

### **4.3 MLS IMPLEMENTATION**

Both lateral and vertical guidance laws have been incorporated in the MD-80 simulation program. The MD-80 yaw damper is simulated without any changes. The basic concept (as discussed in Reference 1) is to generate steering signals based on MLS angles and the DME/P range. These outer loop signals are used as inputs to the DFGS control law inner loops.

The lateral guidance law consists of computing path error and error rate and using these errors to generate the steering signal. A desired path over the ground has been predefined in a waypoint database. MLS angle information and the DME/P range are used to compute the aircraft position in space. Deviations of the aircraft from the desired path are calculated and the appropriate error signals are generated. This mechanization allows the aircraft to follow the desired ground path.

The vertical guidance law similarly computes deviation and rate terms relative to a predefined vertical profile. This vertical profile may be a constant altitude, ascending, descending, or combinations thereof (segmented glide slope). Vertical steering signals command the aircraft to descend at the appropriate time during the approach phase of flight.

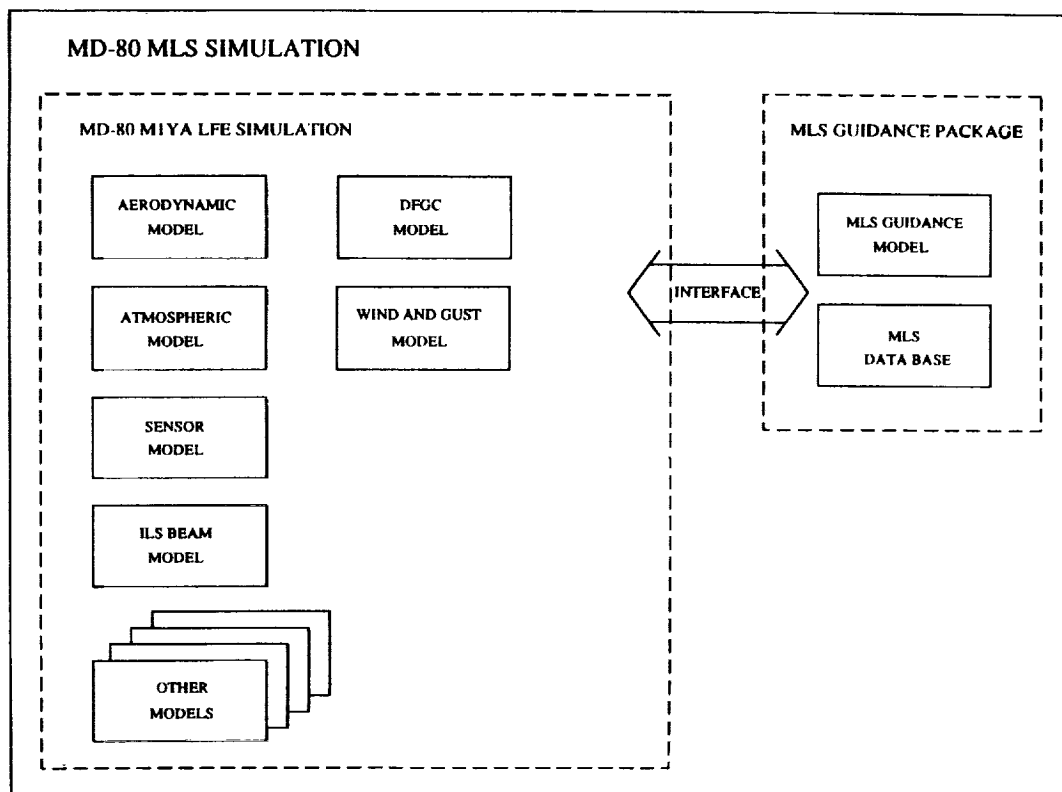


FIGURE 2A. MD-80 MLS SIMULATION INTERFACE

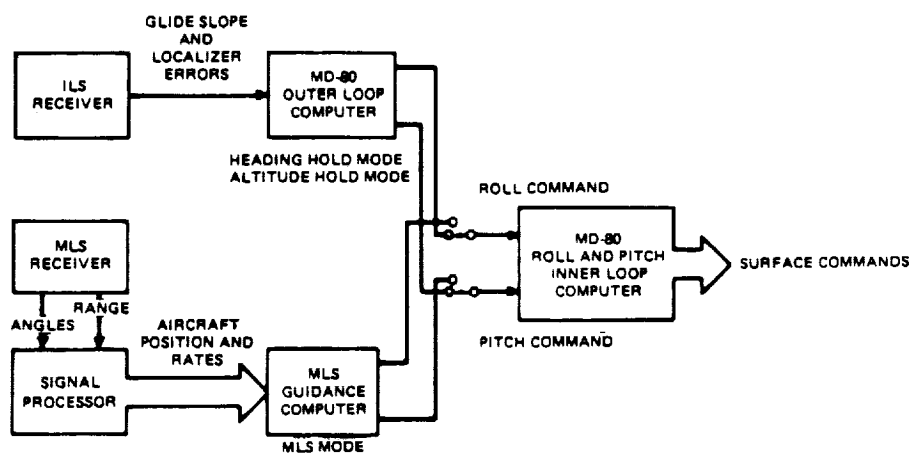


FIGURE 2B. ILS/MLS SWITCHING BLOCK DIAGRAM

## **SECTION 5**

### **MLS PROCEDURES**

Nine approaches were simulated using the MD-80 batch simulation program. One of the approaches was an ILS look alike that emulates existing ILS procedures. Four MLS curved path approaches were considered that were taken from an existing NASA/FAA simulator study currently under way. It is noted that two of these curved path approaches have the azimuth ground station skewed to provide signal coverage throughout the approach. For purposes of the simulation, autoland was not inhibited for these cases. The approaches were flown in order to show automatic landing performance on typical complex paths without accounting for any restrictions on signal coverage. Three trombone approaches (a single 180° turn to the straight final) were added to the data base. A Hong Kong approach was considered and simulated, and a departure was formulated. These latter two MLS procedures posed simulator problems and time constraints prevented analysis of these two cases.

In all cases (except the ILS look alike), MLS curved path guidance was terminated and autoland guidance was armed once the aircraft was established on the final straight segment. Localizer and glide slope captures were initiated after all curved segments were completed. The deviation signals for localizer and glide slope are taken from the MLS receiver. These signals emulate the corresponding ILS signals and are used in place of them for the terminal portion of the approach. This segment of each approach is critical since autoland is armed at this time. If all the autoland criteria are met, then an automatic landing will be completed.

#### **5.1 JFK 31R (ILS LOOK ALIKE)**

The ILS look alike approach at JFK 31R is shown in the Jeppesen plate of Figure 3. This approach was chosen to represent a typical ILS intercept procedure. The lateral and vertical deviations are outputs of the MLS receiver instead of the ILS receivers. An offset to the left of the runway was used as an initial condition, and an angle of 30° was used for localizer intercept. The initial altitude was 2,200 feet. The localizer was captured prior to glide slope capture. A descent on a 3° glide slope was established on the final straight-in segment.

#### **5.2 CURVED PATH APPROACHES**

##### **5.2.1 JFK 13R (Canarsie)**

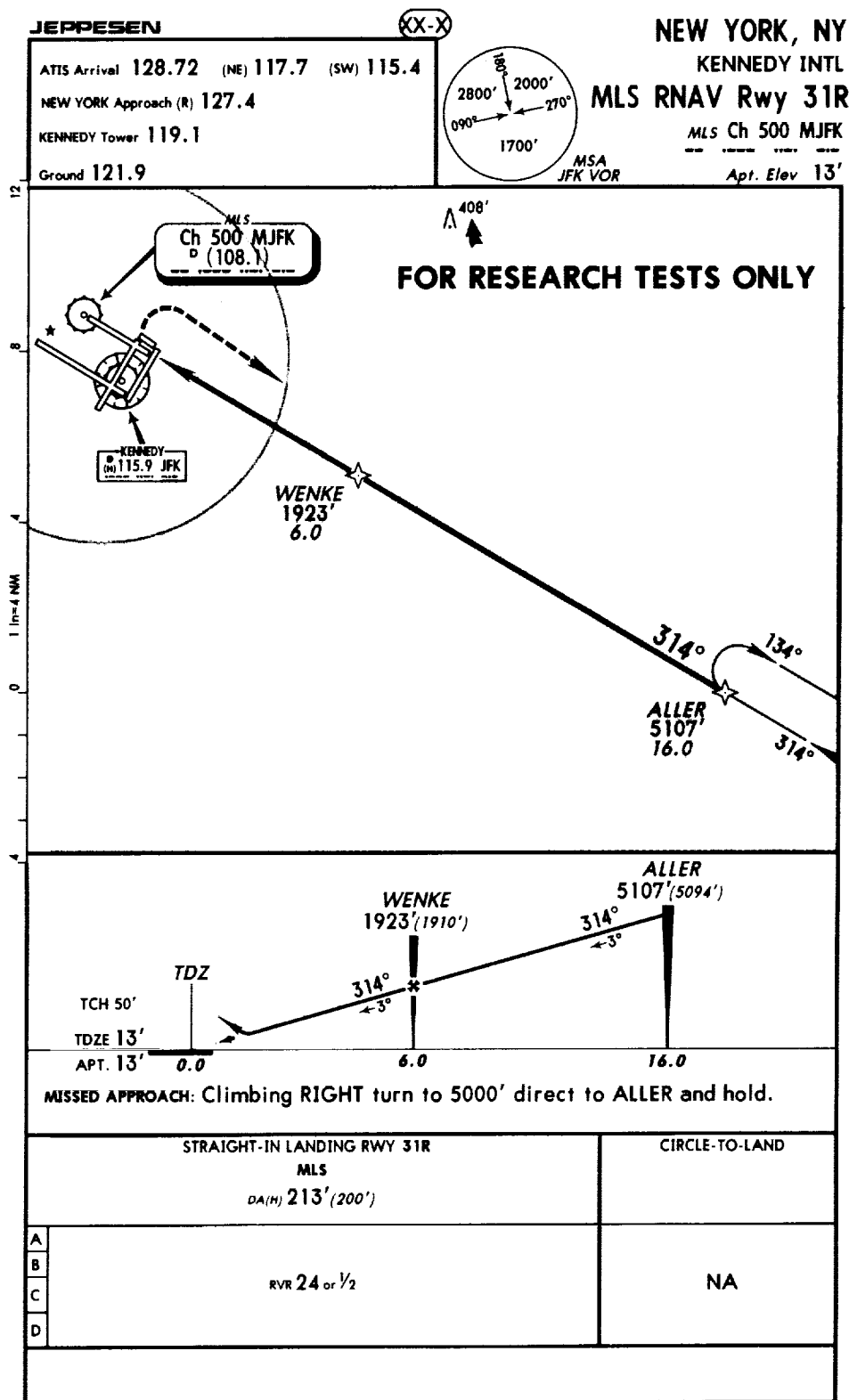
This approach (Figure 4) was selected since it has a 90° turn (7,500 ft turn radius) to final with a short straight final length segment of 1.0 n mi. Currently, the approach is flown using visual procedures. The MLS waypoints and curved segments were selected to define the desired ground track.

##### **5.2.2 DCA 18 (River)**

The River approach is currently flown visually and, like the Canarsie approach, has a 1 n mi final straight segment. Figure 5 depicts the approach. This approach has several closely-spaced turns just prior to the final segment. It was chosen to test the ability of the lateral guidance system to place the aircraft within the required window for autoland.

##### **5.2.3 EWR 11 (The Hook)**

Figure 6 shows this approach which makes two 90° right turns prior to the final left turn at 1.9 n mi. This approach was simulated because it has segmented glide slopes, where the vertical changes occur during the turns.



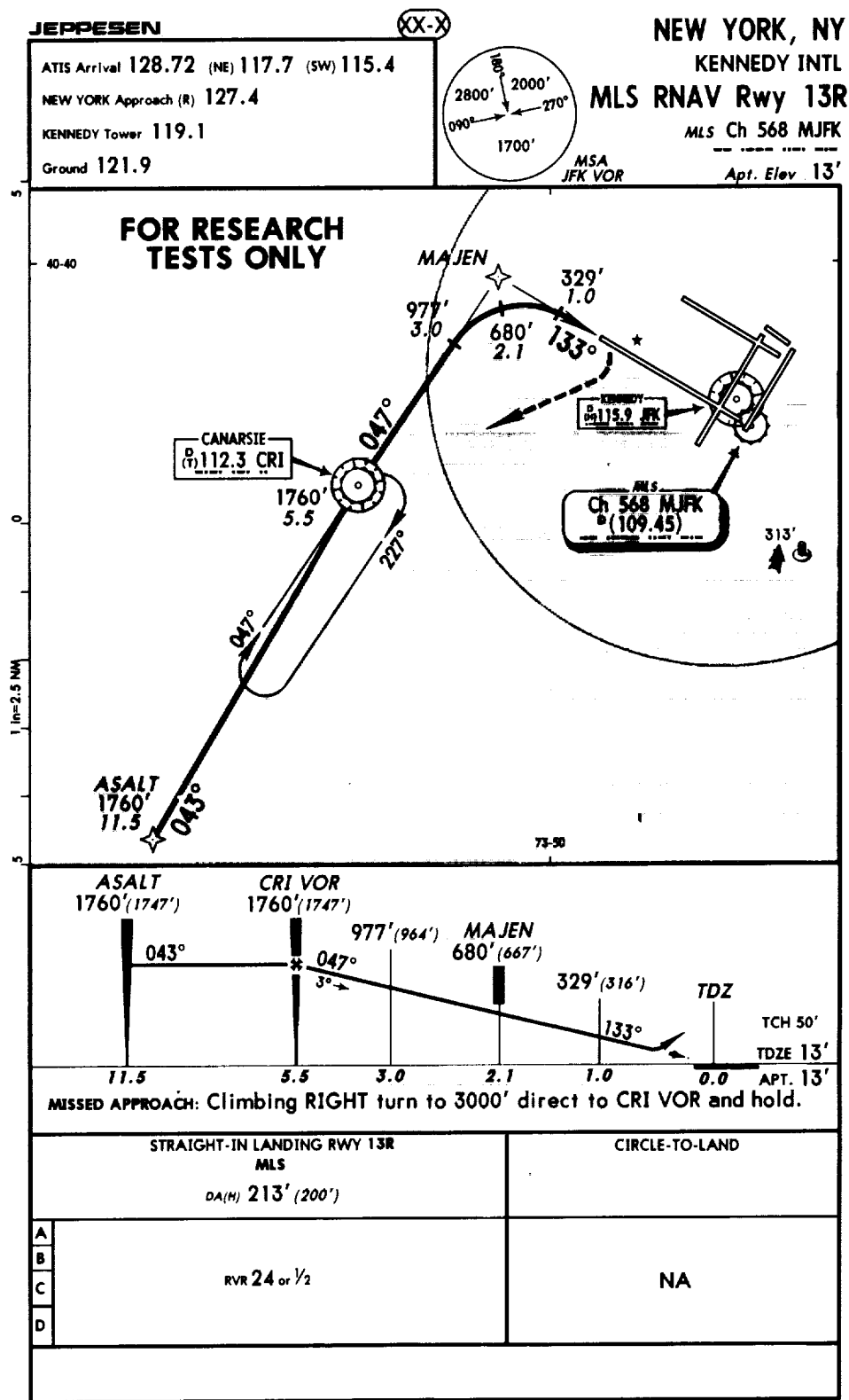
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**FIGURE 3. MLS APPROACH PLATE JFK 31R (ILS LOOK-ALIKE)**





**FIGURE 4. MLS APPROACH PLATE JFK 13R (CANARSIE)**

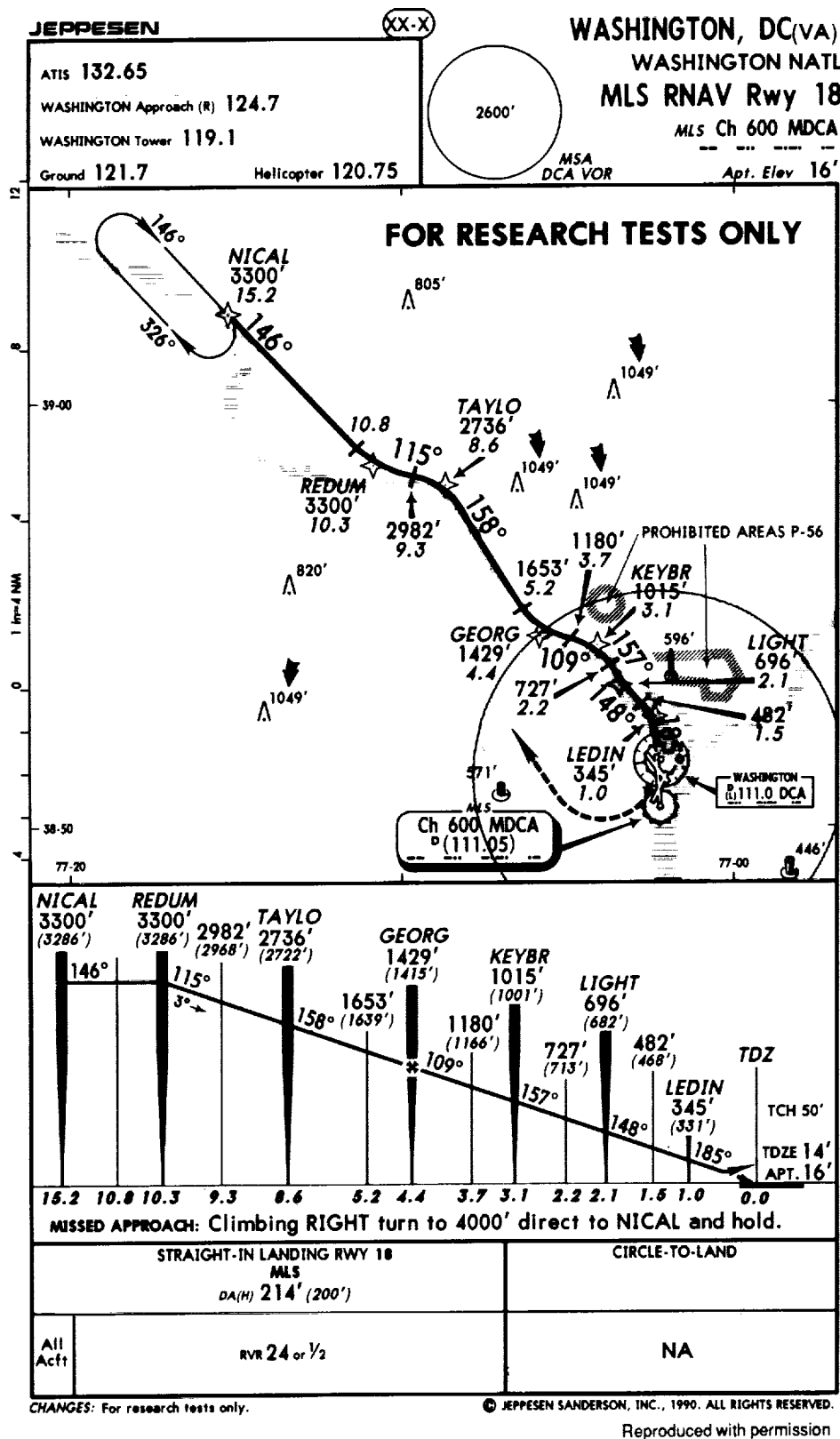
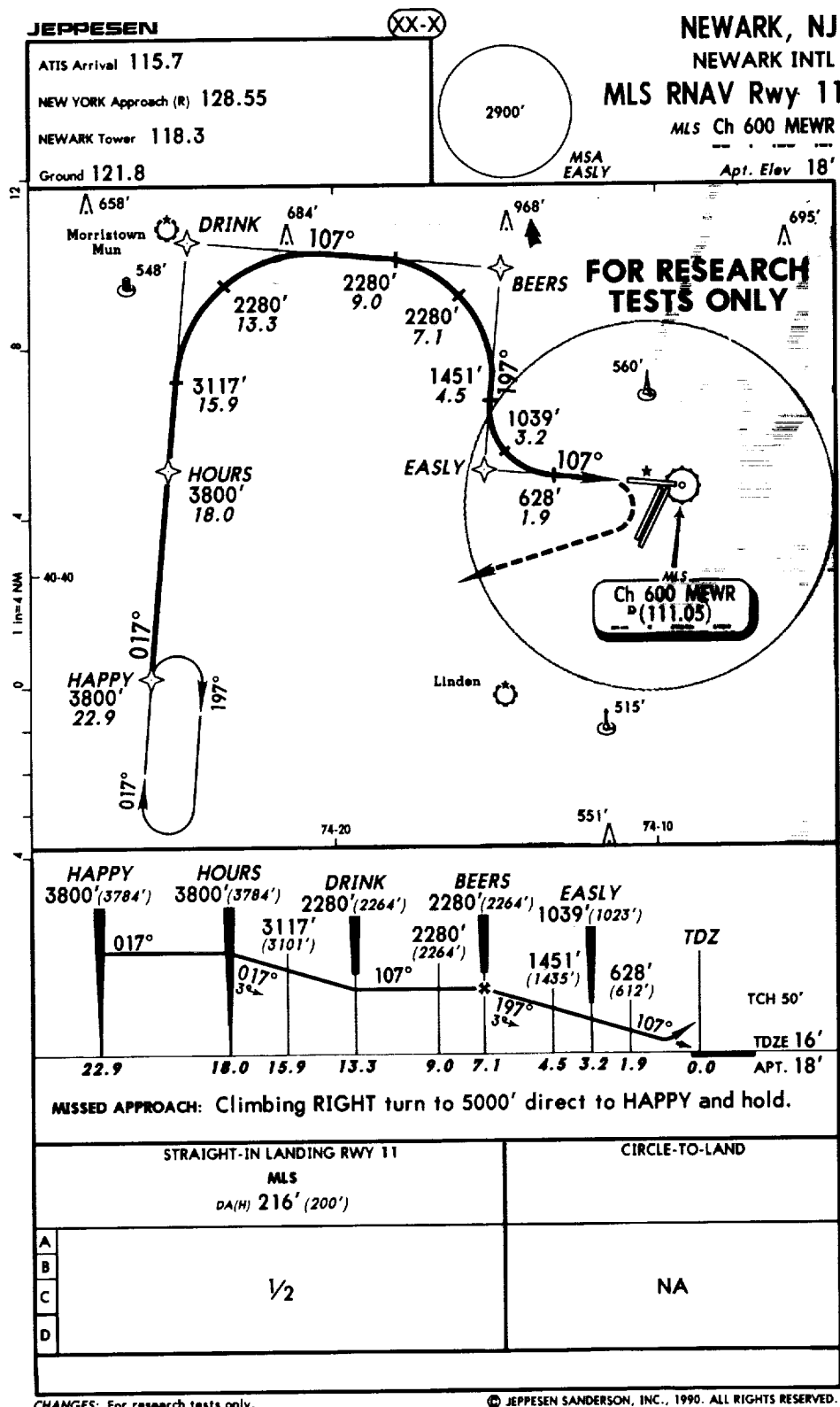


FIGURE 5. MLS APPROACH PLATE DCA 18 (RIVER)



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FIGURE 6. MLS APPROACH PLATE EWR 11 (HOOK)

#### **5.2.4 LGA 13**

This approach (Figure 7) was selected since it has two back-to-back 90° turns with a very short segment between them. This procedure terminates with a 2.7 n mi final, and therefore presents an easier approach than the three previous ones.

#### **5.2.5 Trombones**

Three 'trombone' approaches were set up and simulated. The approaches had a 180° turn to final with a 1-, 2-, and 3-n-mi straight segment. Figure 8 depicts these approaches. These three approaches were not part of the original work statement, and were added at the request of the customer. The reason for including these trombone approaches was to establish the shortest final segment which can be captured and tracked to touchdown without modification to the DFGC control laws.

### **5.3 Departure**

A departure at San Francisco (SFO 28) was simulated that presently is a noise abatement takeoff. Unfortunately, the interface with the MD-80 takeoff logic in the simulation program was not completed successfully. A previous study, documented in Reference 3, discusses takeoff performance for lateral curved path guidance at SFO28. That study used an earlier version of the MD-80 simulation program. Since then, the program has been modified and updated. That process has changed some of the interfaces between the MD-80 coding and the MLS guidance coding. Because of time and resource constraints, the added effort to interface the takeoff logic into the updated program was not undertaken.

JEPPesen

XX-X

NEW YORK, NY

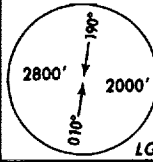
LA GUARDIA

MLS RNAV Rwy 13

MLS Ch 614 MLGA

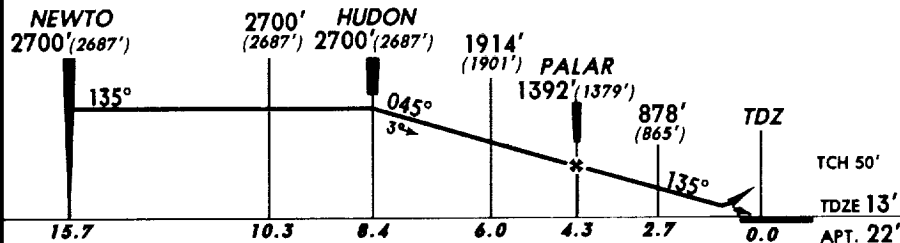
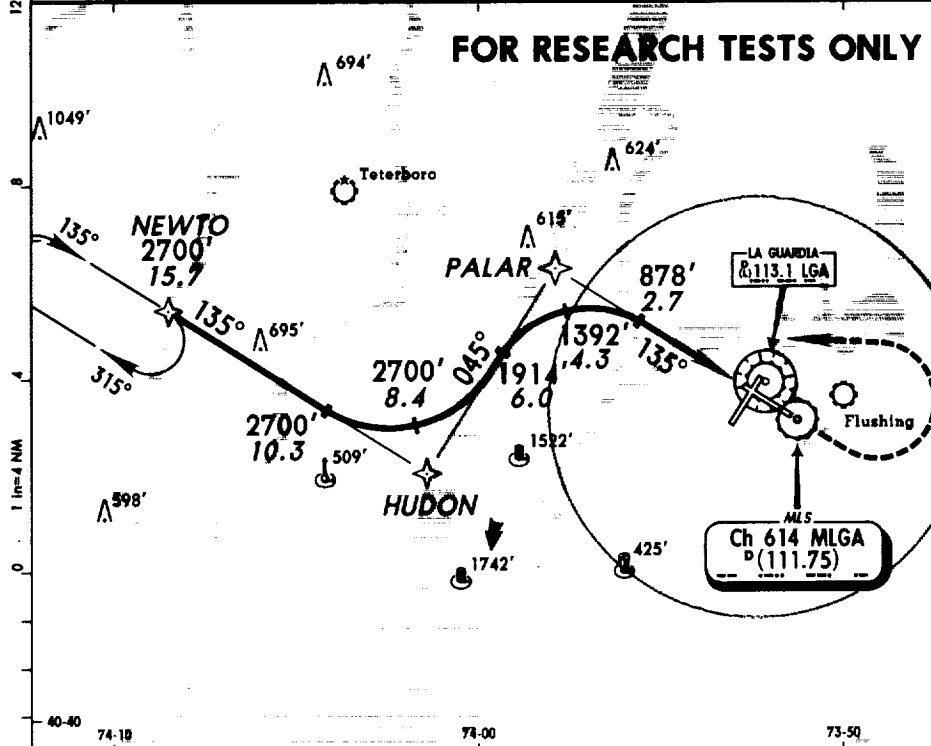
Apt. Elev 22'

ATIS Arrival 125.95  
NEW YORK Approach (R) 120.8  
LA GUARDIA Tower 118.7  
Ground 121.7



MSA  
LGA VOR

FOR RESEARCH TESTS ONLY



MISSSED APPROACH: Climb to 800' then climbing LEFT turn to 3000' direct to NEWTO and hold.

STRAIGHT-IN LANDING RWY 13		CIRCLE-TO-LAND	
MLS			
DA(M) 213' (200')			
A	RVR 24 or 1/2	NA	
B			
C			
D			

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FIGURE 7. MLS APPROACH PLATE LGA 13 (OFFSET)

# TROMBONE APPROACHES

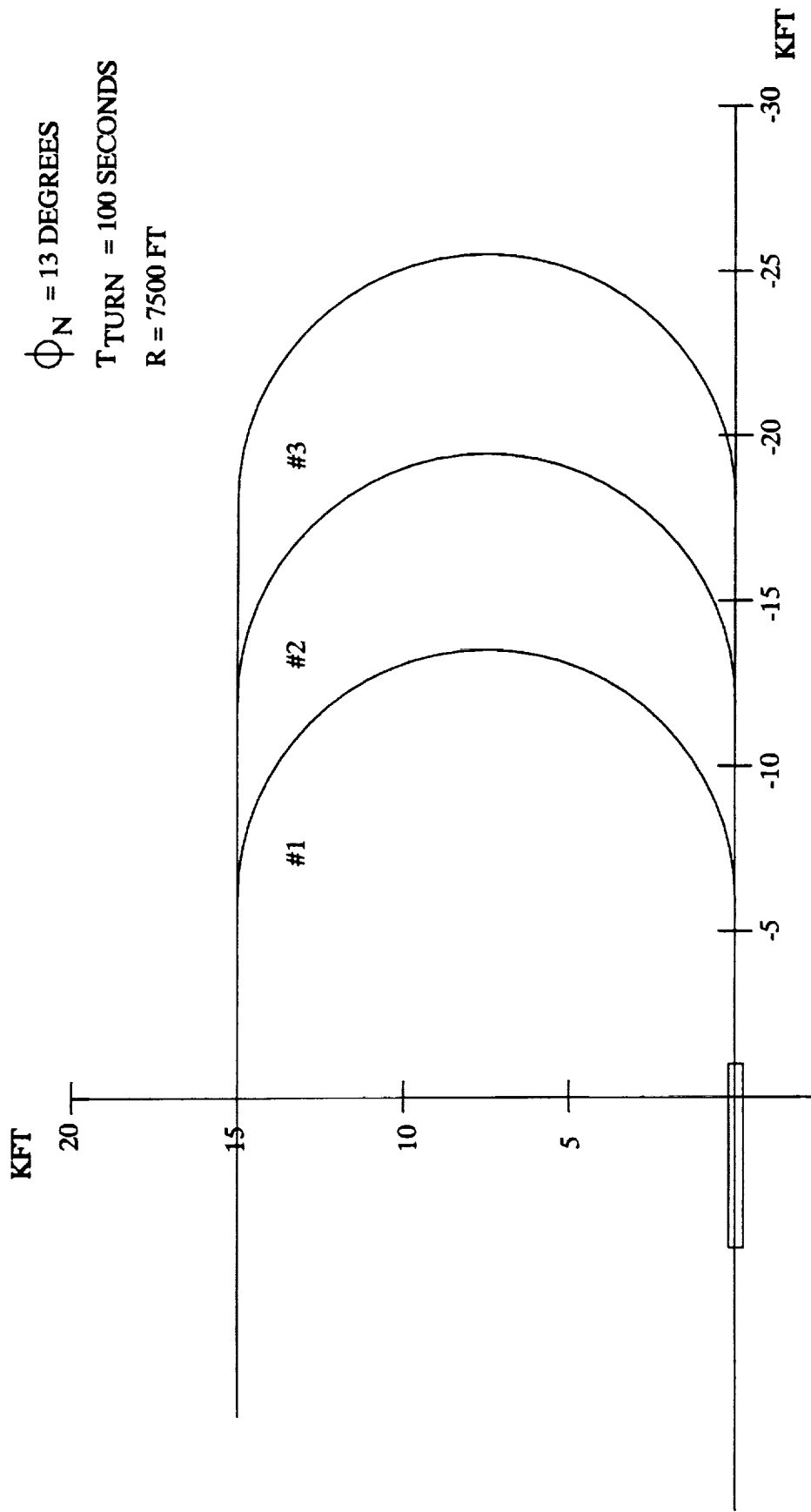


FIGURE 8. TROMBONE APPROACHES

## SECTION 6 SIMULATION RESULTS AND ANALYSIS

### 6.1 AUTOLAND PASS-FAIL CRITERIA

The current MD-80 DFGC automatic landing mode has been certified to meet the requirements of AC 20-57A, which governs automatic landing systems, and AC 120-28C, which governs CAT III landing weather minima. The following limitations are applicable to simulation data collected, and have been used to establish a pass-fail criteria for all approaches conducted in this study. It should be noted that study results do not apply to, nor are defined to meet landing dispersion criteria, as only a single approach and configuration was used to produce the touchdown data.

1. The maximum lateral displacement (offset) from the runway centerline shall not result in the outboard landing gear being closer than 5 ft from the edge of a 150 ft runway for one in  $10^6$  landings. (See Figure 9.) In reference to the MD-80 landing gear dimensions, this requirement is equivalent to the placement of the aircraft centerline no more than 59.8 ft from the runway centerline.
2. No more than one in  $10^6$  landings shall be shorter than 200 ft, nor longer than 2,495 ft past the runway threshold. This second distance is equivalent to the position at which the pilot can see at least 4 bars of the 3,000 ft touchdown zone lights. Both of these requirements apply to the main gear touchdown point.

In comparison, though not applicable to study data results, touchdown dispersion data collected during the MD-80 autoland certification program meets the two sigma (95% probability) requirements defined in AC 2057A. Included in these requirements are:

- Maximum lateral displacement of 27 ft from the runway centerline.
- Maximum longitudinal displacement no shorter than 500 ft, nor longer than 2,000 ft past the runway threshold.

No explicit FAA requirements govern the following items; however, the following are considered to be limitations, either to aircraft structural tolerances, or operational procedures which have been included as part of the pass-fail criteria:

1. The maximum lateral velocity at touchdown shall not compromise the structural integrity of the aircraft main landing gear.
2. The maximum vertical velocity (sink rate) at touchdown shall not compromise the structural integrity of the aircraft main landing gear.
3. Passenger acceptance limits the vertical velocity at touchdown to about 4 ft/sec, with a design goal of 2 ft/sec.
4. In order to evaluate the approach as an autoland, LOC TRK and GS TRK must be attained, with autoland criteria satisfied, above 300 ft AGL in order to fulfill the minimum requirements for autoland, as applicable to this study.

Any approach not meeting the aforementioned criteria is to be considered unsuccessful. Any criteria, such as that defined by AC 20-57A or 120-28C which is not met will compromise the current autoland certification, and therefore must be strictly adhered to.

# AUTOLAND TOUCHDOWN DISPERSION REQUIREMENTS

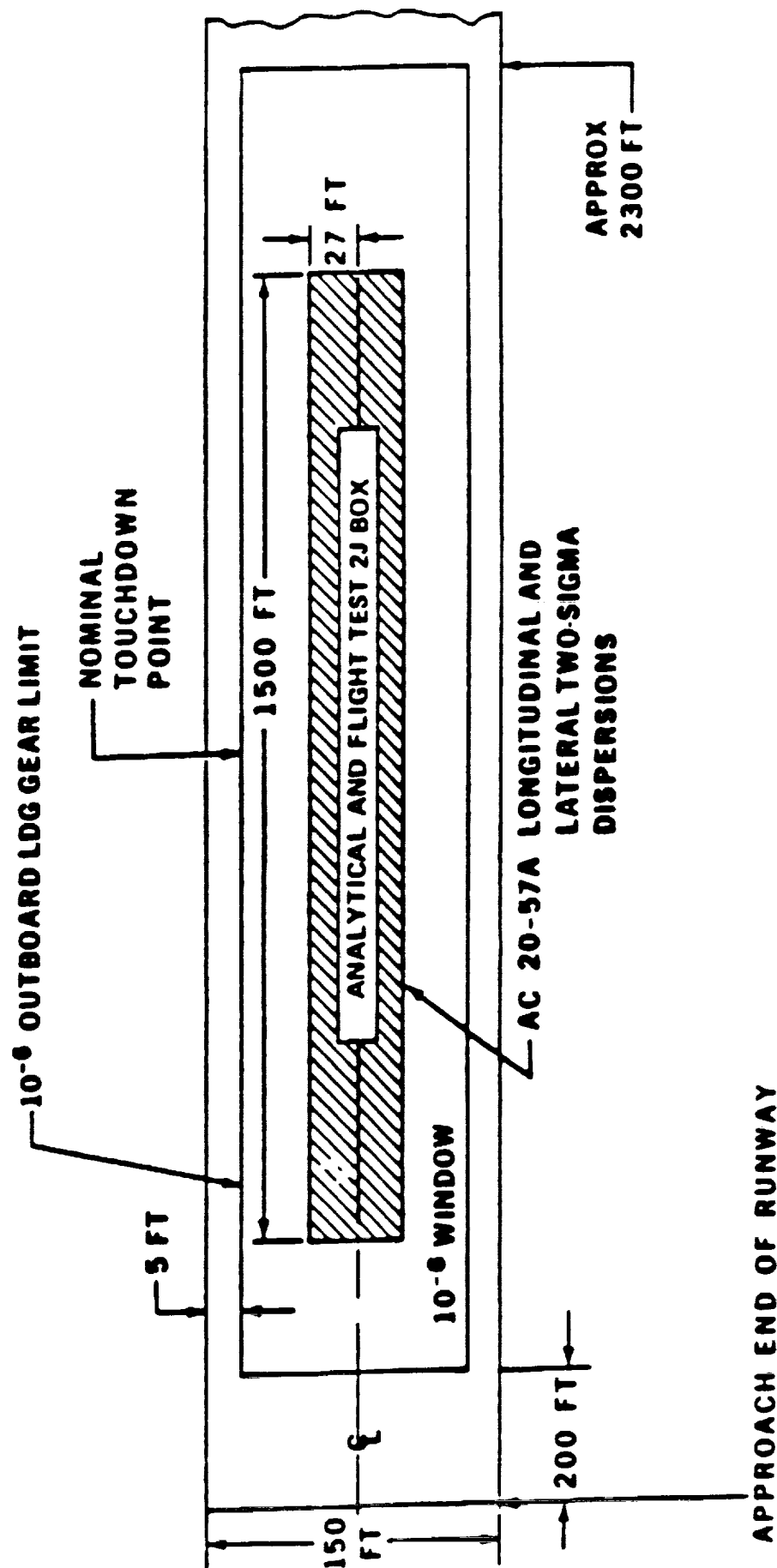


FIGURE 9. AUTOLAND, TOUCHDOWN DISPERSION/FOOTPRINT REQUIREMENTS



## 6.2 SIMULATION RESULTS

In order to maintain an MLS curved ground track throughout all the approaches, the transition from MLS guidance to ILS angle tracking guidance has been inhibited until the aircraft has rolled out onto the final straight segment. As a result of this implementation, localizer capture (as well as glide slope capture) cannot occur prior to reaching this point of the approach. In addition, current DFGC lateral approach control laws feature a time delay inhibiting localizer tracking for 10 seconds following localizer capture. This delay allows localizer complementary filter output stabilization to occur prior to localizer tracking.

For the study aircraft configuration, at an approach speed of 140 kts and on a  $3^\circ$  glide slope, a 10 second time delay equates to approximately 130 ft of altitude loss. Therefore, in order to meet the 300 ft lower limit for localizer track engagement, localizer capture must occur no lower than approximately 430 ft. This configuration was not meant to represent a worst case, but only a typical MD-80 autoland approach.

Table 1 depicts a summary of pertinent data collected for each MLS curved path approach. Included in this table are along track distances from the glide slope ground intercept point and the associated altitudes for each approach milestone. Also, touchdown foot print data used to evaluate the performance of the aircraft is included. This touchdown data represents a single simulation run for each approach listed.

Upon review of the study approaches shown in Table 1, the Canarsie, the DCA River, as well as the 1 mile trombone achieved localizer track engagement well below 300 ft. Further analysis shows that all of the aforementioned approaches feature localizer captures significantly below the 430 ft minimum altitude defined previously. When this criteria is applied to the remaining approaches (ILS look alike, the hook, LGA 13, and the 2 and 3 mile trombones), localizer captures occurred above 430 ft. As a result, subsequent localizer tracking was achieved above 300 ft, yielding better touchdown performance. A follow-on study which investigates reduced time delays between localizer capture and tracking might prove to be beneficial. In addition, from a passenger comfort viewpoint, the Canarsie and River approaches have lateral touchdown velocities that exceed 5 ft/sec. This velocity level (in excess of 5 ft/sec) is considered to be unacceptable to passengers, but is based on past experience and should be used as a guideline only.

### 6.2.1 JFK 31R (ILS Look Alike)

Figure 10 shows the lateral tracking of the ILS look alike, where intercept of the final segment occurs at a  $30^\circ$  angle to the extended runway centerline. The runway is located at the origin for this approach and the other approaches to be discussed later. The solid line is the desired lateral track. (For the ILS approach, this track is defined by straight lines correcting the waypoints.) The dashed line represents the actual track of the aircraft during the approach. Asymptotic capture can be seen to occur before localizer tracking is established on the final leg (at a distance of about 55,000 ft, or 9 n mi), which corresponds to the LOC TRK entry for the ILS look alike in Table 1.

The vertical profile, Figure 11, shows the solid line depicting altitude hold until about 42,000 ft along track distance, at which time it intersects the  $3^\circ$  glide slope line. The dashed line shows the asymptotic capture of the glide slope. The graph's x-axis terminates at zero along track distance. Flare and touchdown occur at a later time, and consequently are off scale. The autopilot performed

## TABLE 1

## MD-80 MLS BASELINE PERFORMANCE AUTOLAND ARM ON FINAL LEG OF MLS APPROACH

WT=132,000 LBS, FLAPS=40, VE=140 KNOTS, CG=25%, NO WIND UNLESS SPECIFIED

MLS FLIGHT PATH	GS CAPTURE		GS TRACK		LOC CAPTURE		LOC TRACK		ALIGN		FLARE		FOOTPRINT AT TOUCHDOWN				
	NM	ALT(FT)	NM	ALT(FT)	NM	ALT(FT)	NM	ALT(FT)	NM	ALT(FT)	NM	ALT(FT)	LAT. OFF-SET FT	LONG. OFF-SET FT	LAT. VEL FT/S	VERT. VEL FT/S	THETA DEG
JFK 31R ILS LOOK ALIKE	7.24	2188	6.64	2099	10.59	2188	9.03	2190	0.48	145	0.17	48	4.00	447	-0.10	-3.80	7.00
JFK 13R CANARSIE	1.15	356	1.15	356	1.15	356	0.55	166	----	----	----	----	8.00	362	-5.40	-4.00	7.20
DCA RIVER APPROACH	0.62	185	0.62	185	0.62	185	0.08	23	----	----	----	----	36.00	389	-5.80	-3.80	7.90
WITH 15 KT WIND	0.63	192	0.63	192	0.59	181	0.04	13	----	----	----	----	30.00	380	-8.20	-4.00	8.20
WITH -15 KT WIND	0.63	182	0.63	182	0.63	182	0.19	32	----	----	----	----	30.00	372	-2.90	-4.00	7.80
EWR 11 THE HOOK	1.91	592	1.91	592	1.91	592	1.31	402	0.49	145	0.18	49	-5.00	328	-3.20	-3.80	7.00
LGA 13 APPROACH	2.71	849	2.71	849	2.71	849	2.32	721	0.51	150	0.17	47	-2.00	377	0.80	-3.80	7.00
1 MILE TROMBONE	0.96	304	0.96	304	0.96	292	0.40	117	-----	----	-----	----	-5.00	371	-0.10	-3.90	7.20
2 MILE TROMBONE	1.98	618	1.98	618	1.98	618	1.40	432	0.51	149	0.18	48	13.00	321	3.50	-3.70	7.00
WITH 15 KT WIND	1.99	626	1.99	626	1.99	626	1.38	425	0.49	145	0.19	49	2.00	262	3.10	-3.40	7.40
WITH -15 KT WIND	1.99	616	1.99	616	1.99	616	1.43	442	0.49	146	0.19	49	10.00	267	3.70	-4.10	7.60
3 MILE TROMBONE	2.98	938	2.98	938	2.98	938	2.60	811	0.49	145	0.18	50	-4.00	423	1.30	-3.80	7.00

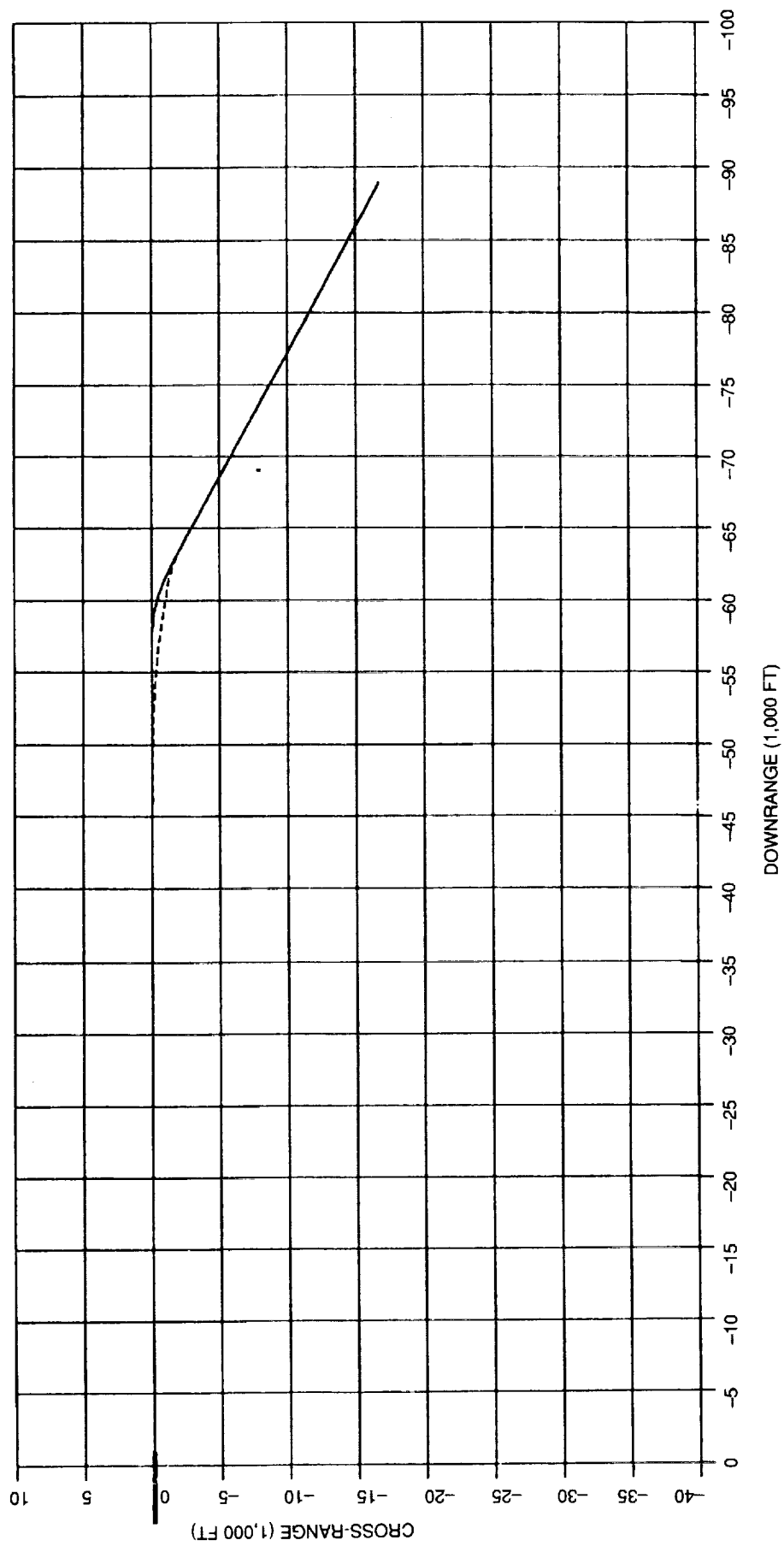


FIGURE 10. GROUND TRACK FOR JFK 31R

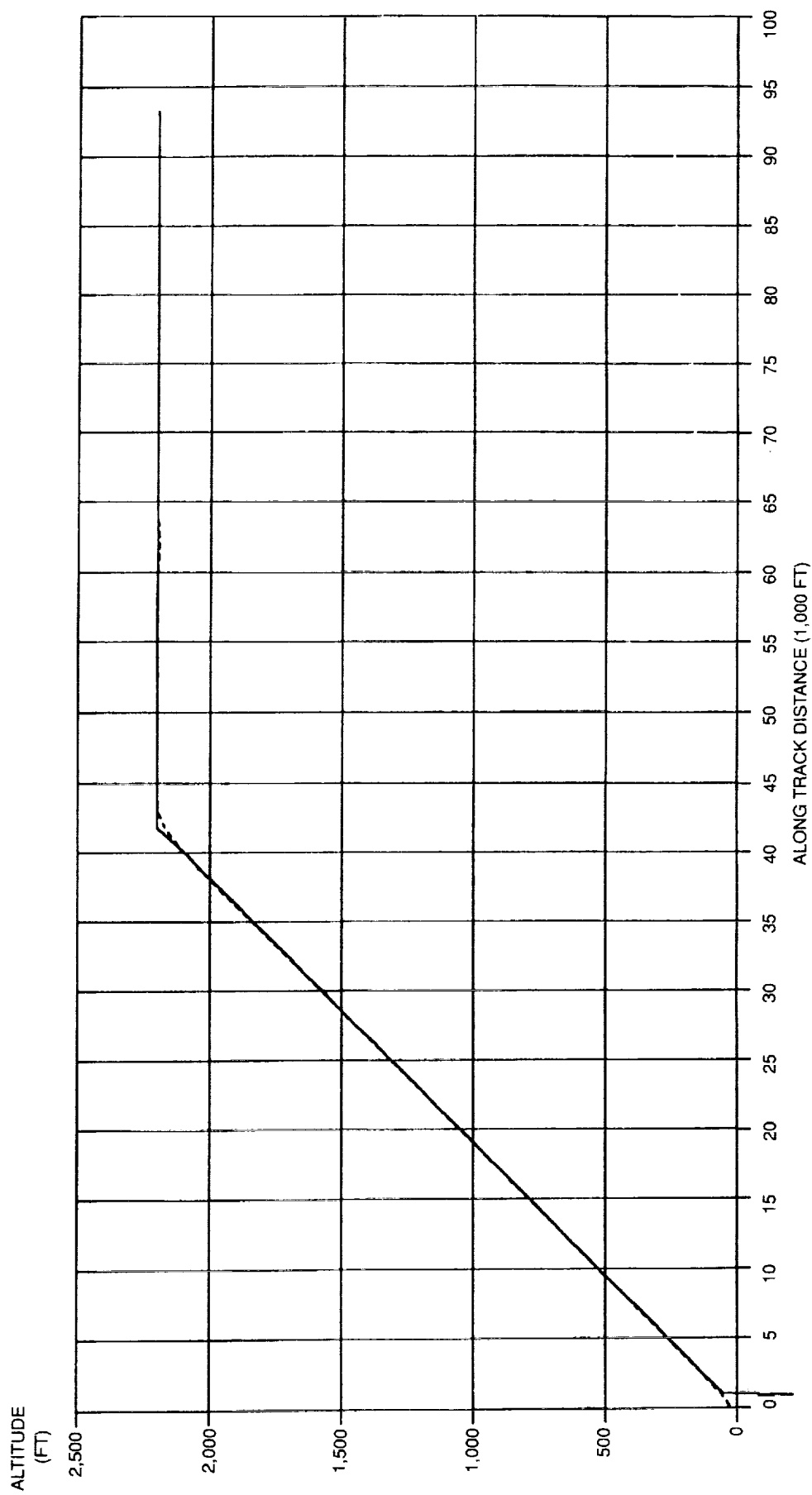


FIGURE 11. VERTICAL PROFILE FOR JFK 31R

exactly as an ILS approach would, both laterally and vertically. The only difference here is the localizer and glide slope deviations are directly from the MLS receiver instead of the ILS receiver.

## **6.2.2 Curved Path Approaches**

Results for the five curved path MLS approaches simulated in this study are discussed in the following sections.

**6.2.2.1 JFK 13R (Canarsie)** — Ground track for this approach is shown in Figure 12. At the scale shown, no difference between the desired track and actual track is apparent. An expanded-scale plot (Figure 13) shows details of the terminal segment. The tracking error is now apparent during the turn. At about 7,500 ft, the localizer capture mode is initiated, and the error during capture and track can be seen. A short final such as in this approach affects the localizer tracking performance. The error and error rates, as well as the bank angle, must be stabilized before track can take place.

Figure 14 shows the vertical profile for Canarsie. Tracking is smooth all along the 3° descent.

**6.2.2.2 DCA 18 (River)** — The final three turns for the river approach are shown in Figure 15. As in the Canarsie approach, the River presents tracking problems because of the short-radius turns just before final straight segment. An offset at the threshold is apparent in the figure. Crosswinds of +15 kt at touchdown were simulated, and the results are shown in Figures 16 and 17. A +15 kt crosswind is from the aircraft's left side when on final approach. Although a definite deviation in the aircraft ground track from the no-wind case is obvious, the lateral offset at touchdown for all three cases are almost the same. (See Table 1 entries for the River approach.) The lateral guidance system compensates for the wind — induced error during this final segment.

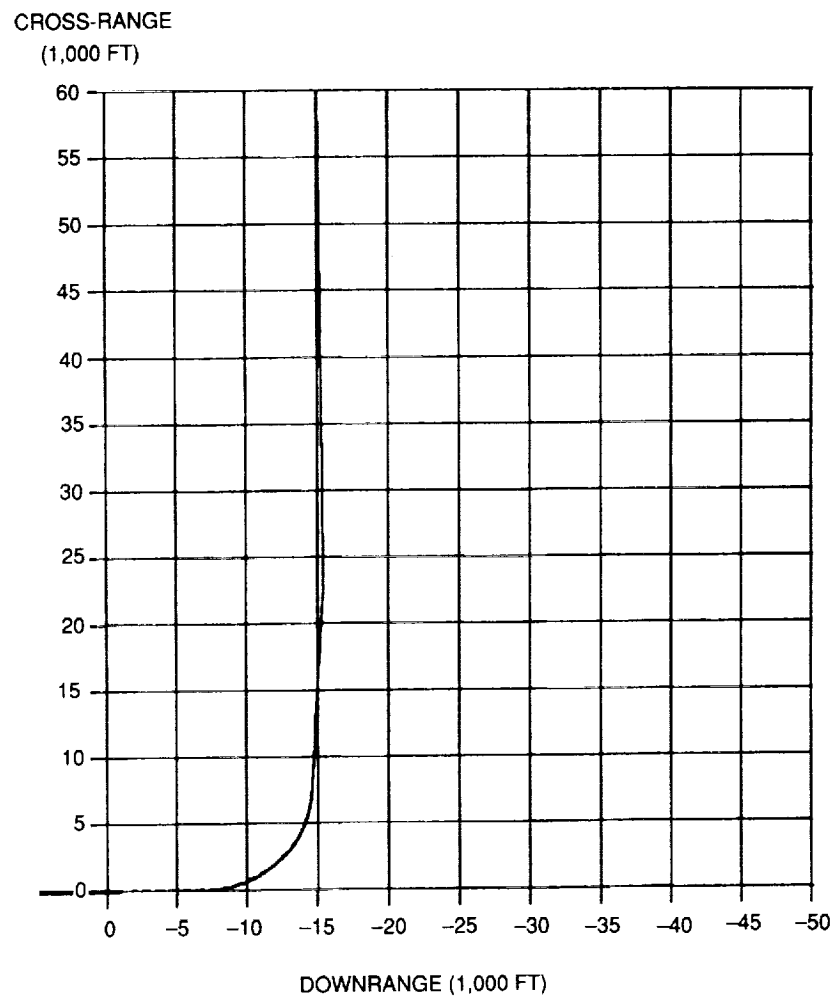
**6.2.2.3 EWR II (The Hook)** — Since this approach has a larger final straight segment than either Canarsie or the River, the lateral offset at touchdown is much smaller, on the order of 5 feet (Figure 18). This approach was designed to contain glide slope changes during turns. The vertical profile for this case is shown in Figure 19. It was thought that the system might have tracking problems by having to change glide slope when in a turn. The autopilot had no such problems, and consequently both vertical tracking and lateral tracking errors were small.

**6.2.2.4 LGA 13 (Offset)** — This approach had the longest final straight segment (2.7 n mi); as a result, small lateral and vertical tracking errors were maintained both at touchdown as well as during the S-turns prior to the final segment. Figures 20 and 21 show the ground track and vertical profile for this approach.

**6.2.2.5 Trombone** — Lateral and vertical profiles for the trombone approaches are illustrated by the one mile final as shown in Figures 22 and 23. The 2 and 3 mile trombone approaches are such that localizer track will occur above 300 ft altitude and hence autoland will be completed. The one mile trombone, however, violates the 300 ft criterion and therefore autoland would be inhibited due to the logic as presently implemented in the MD-80 DFGC. Based on this criterion, a 2 mile or longer final would be required using the present MD-80 autoland system for these types of approach paths.

## **6.3 LANDING GEAR LOAD ANALYSIS**

A landing gear analysis was performed by the Douglas MD-80 Airframe Definition and Design Group in order to evaluate the worst case structural loads imposed on the aircraft main landing gear,



**FIGURE 12. GROUND TRACK FOR JFK 13R**

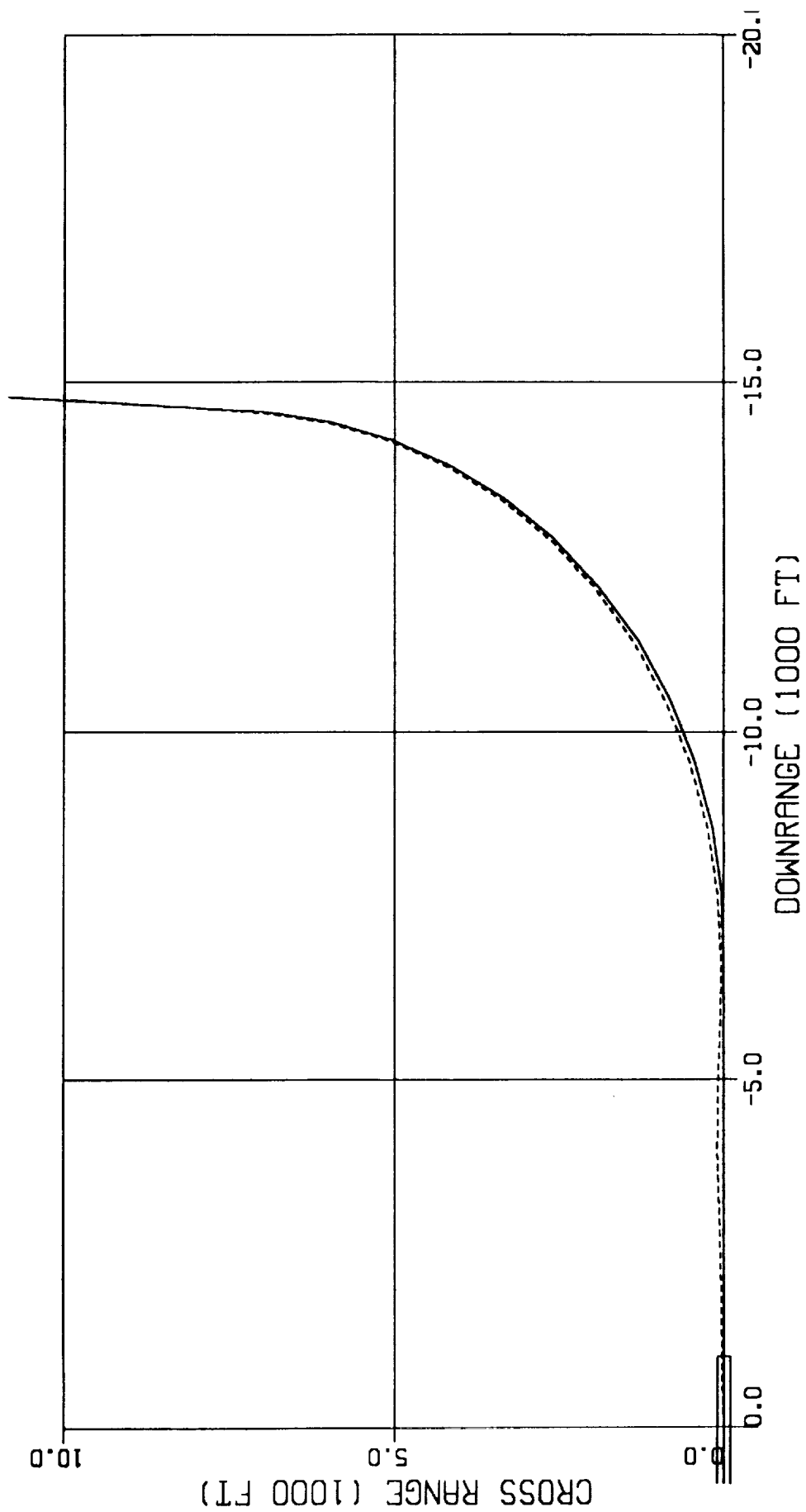


FIGURE 13. GROUND TRACK FOR JFK 13R (EXPANDED SCALE)

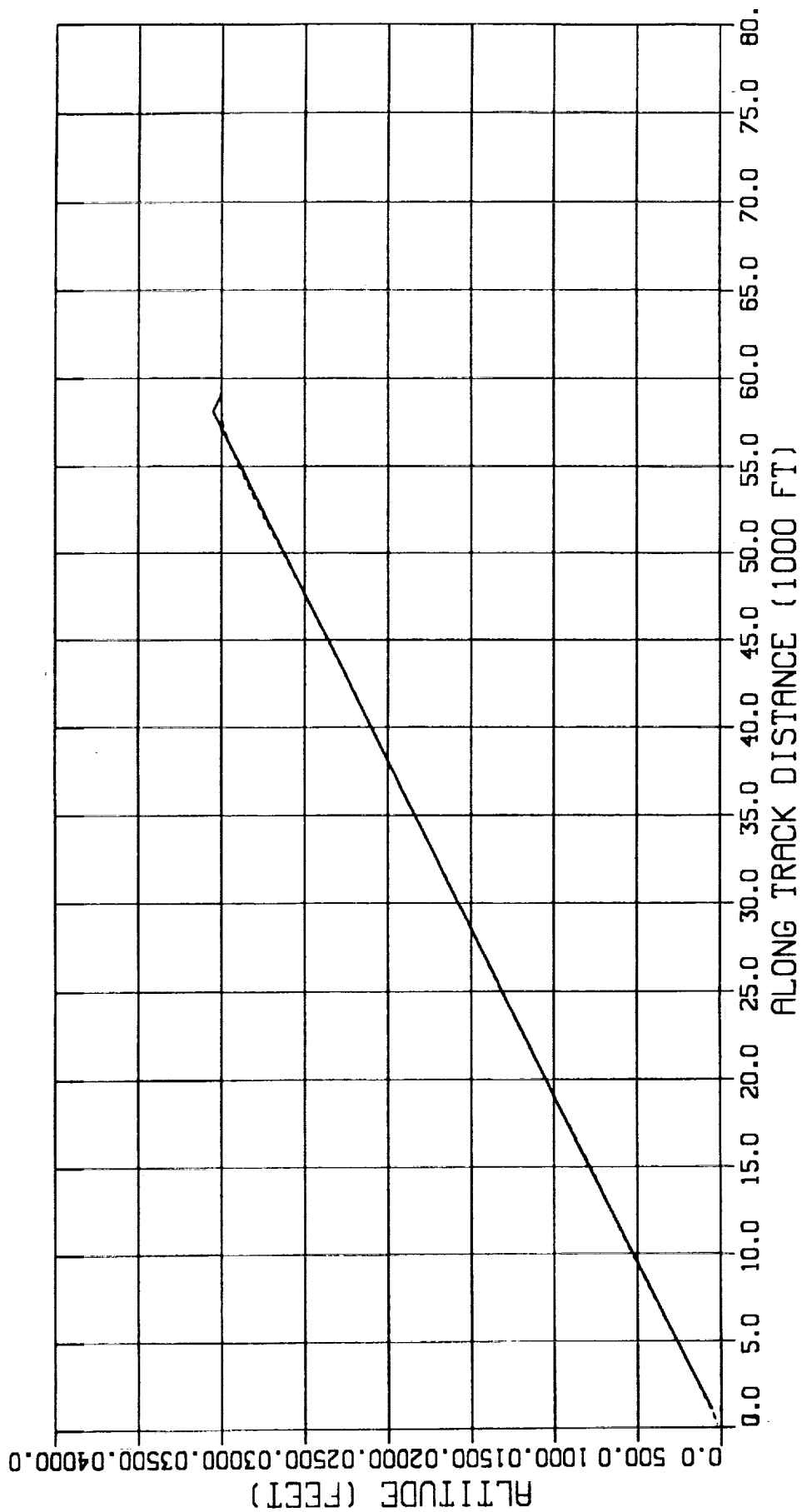


FIGURE 14. VERTICAL PROFILE FOR JFK 13R



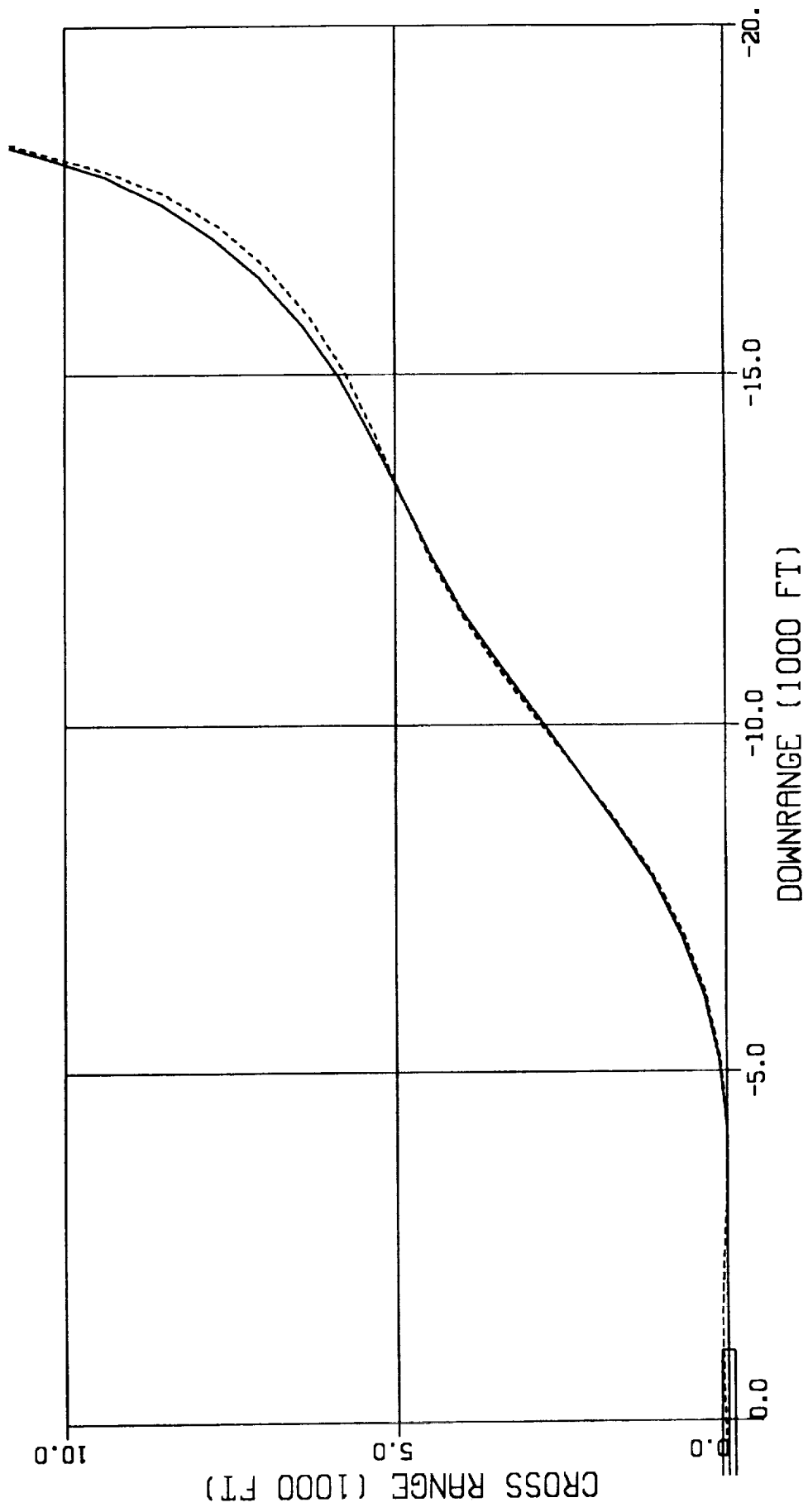


FIGURE 15. GROUND TRACK FOR FINAL APPROACH AT DCA 18 (NO WIND)

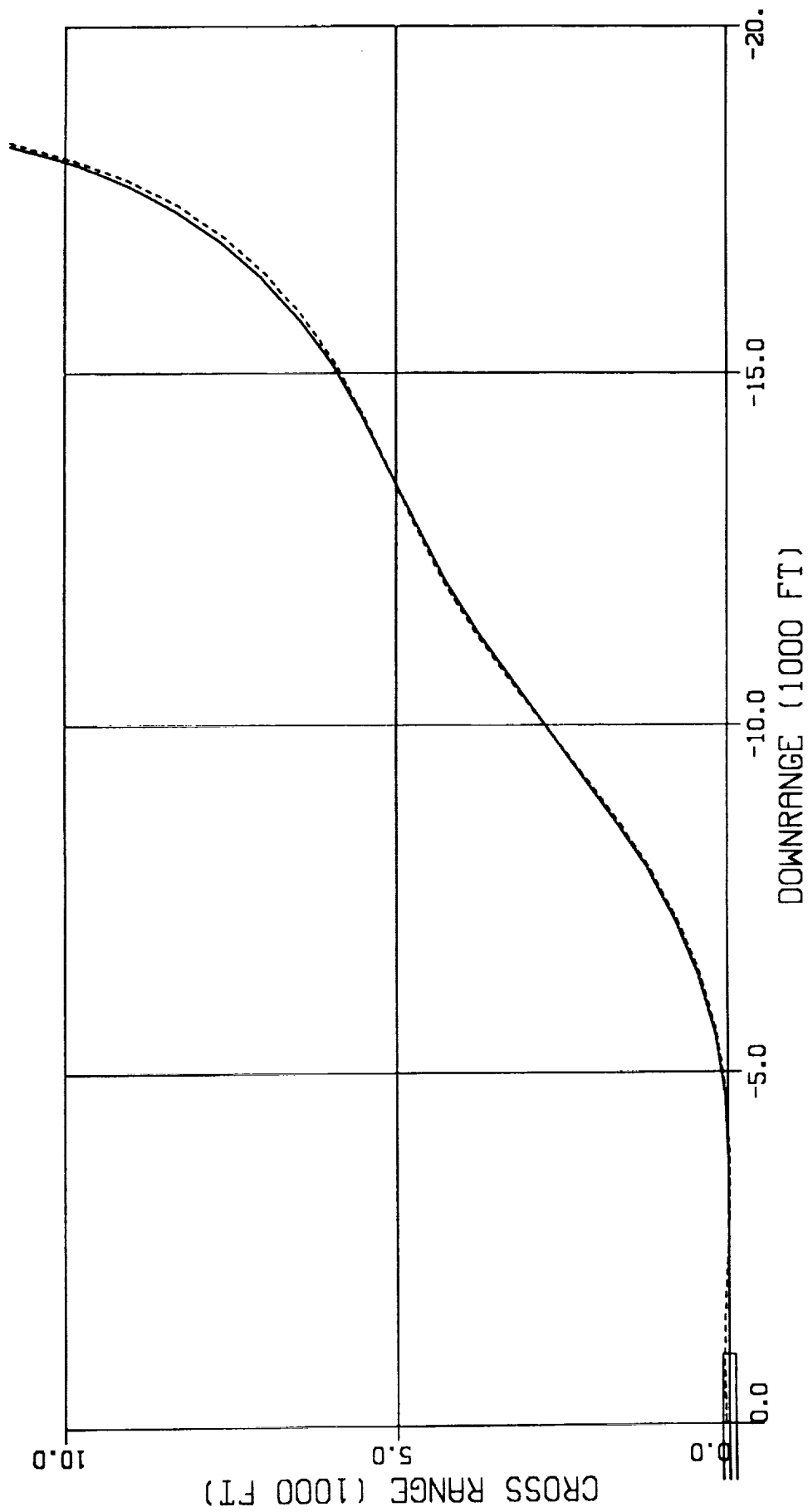


FIGURE 16. GROUND TRACK FOR FINAL APPROACH AT DCA 18 (15-KNOT CROSSWIND FROM THE LEFT)

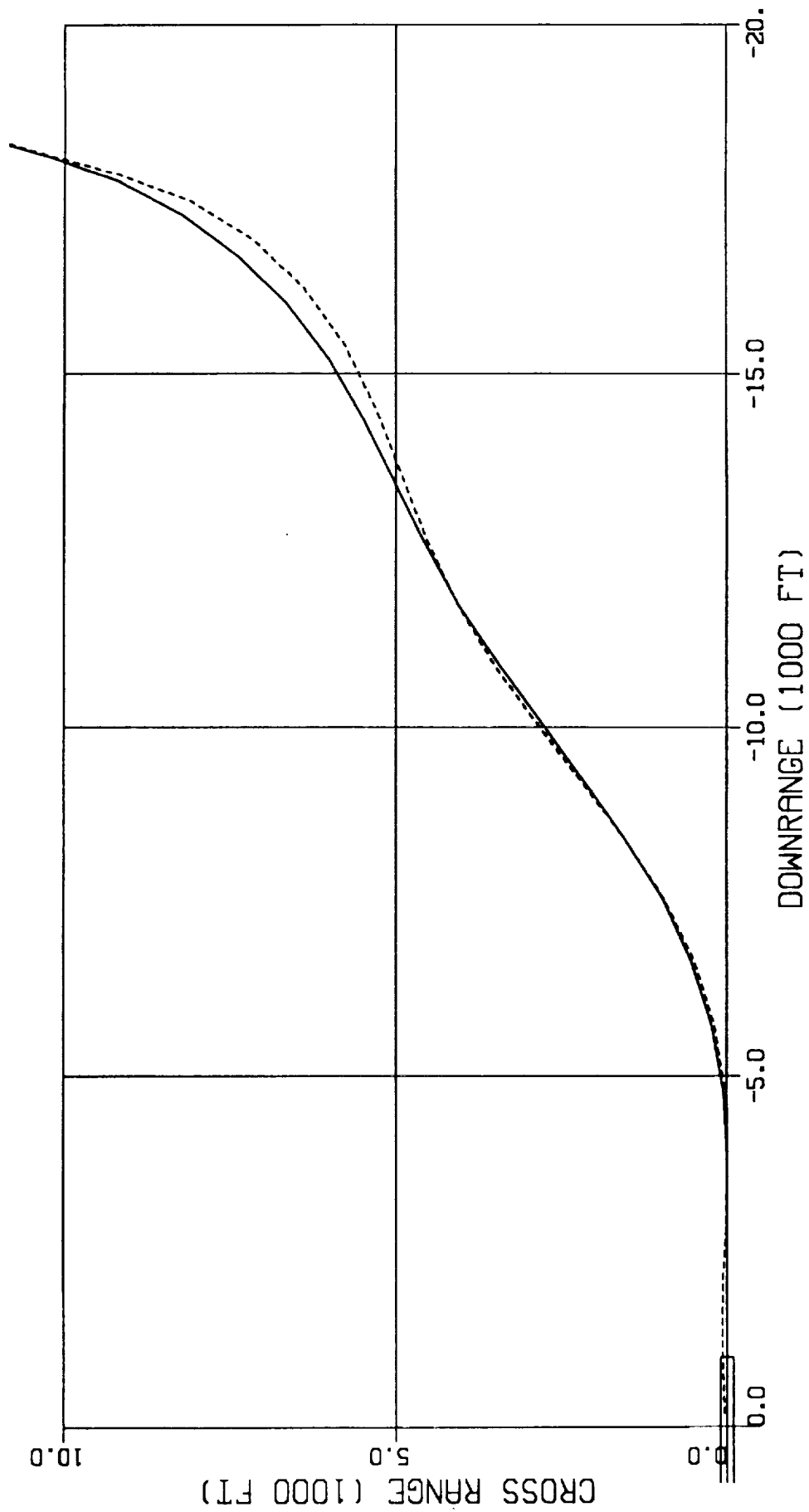


FIGURE 17. GROUND TRACK FOR FINAL APPROACH AT DCA 18 (15-KNOT CROSSWIND FROM THE RIGHT)

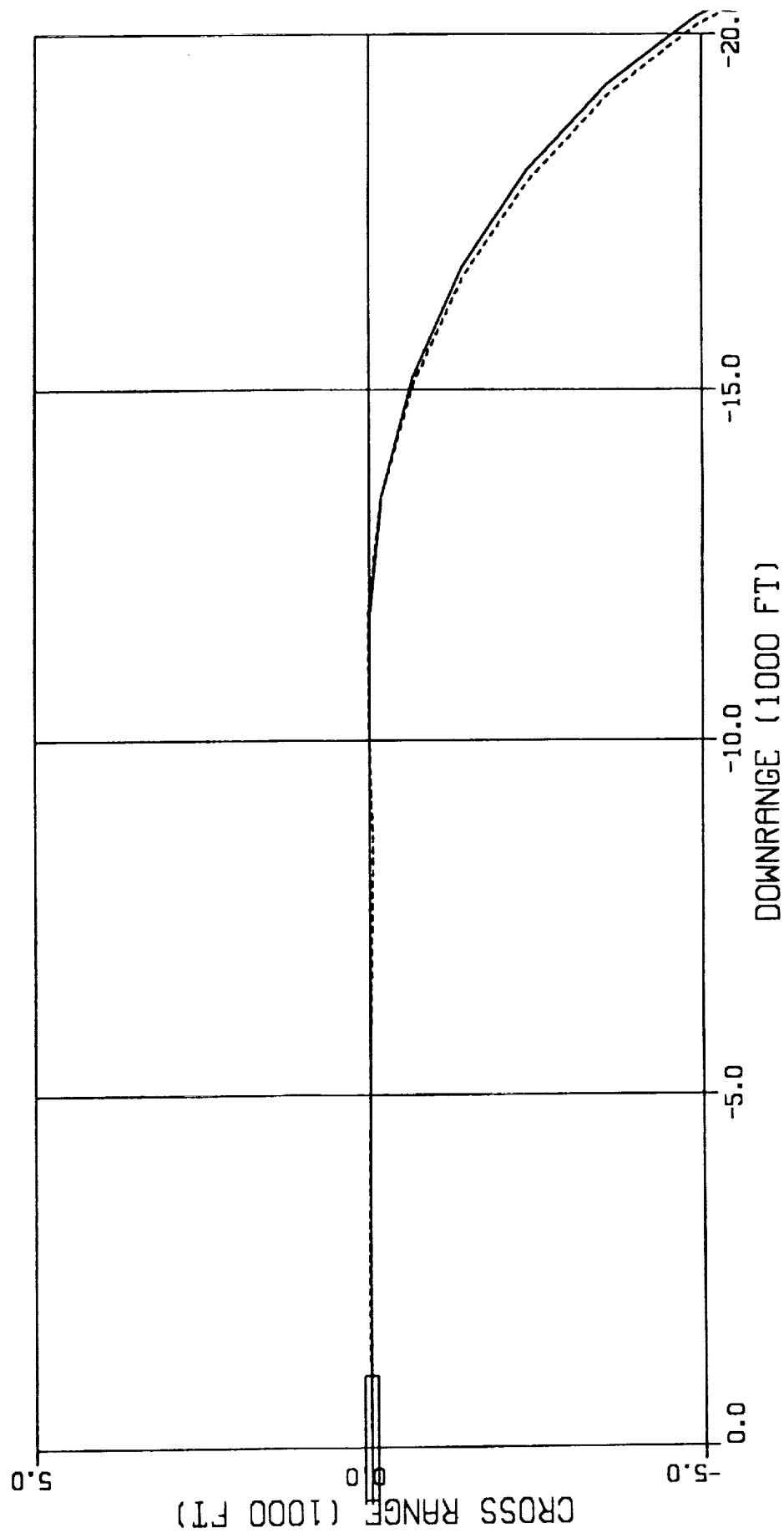


FIGURE 18. GROUND TRACK FOR EWR 11

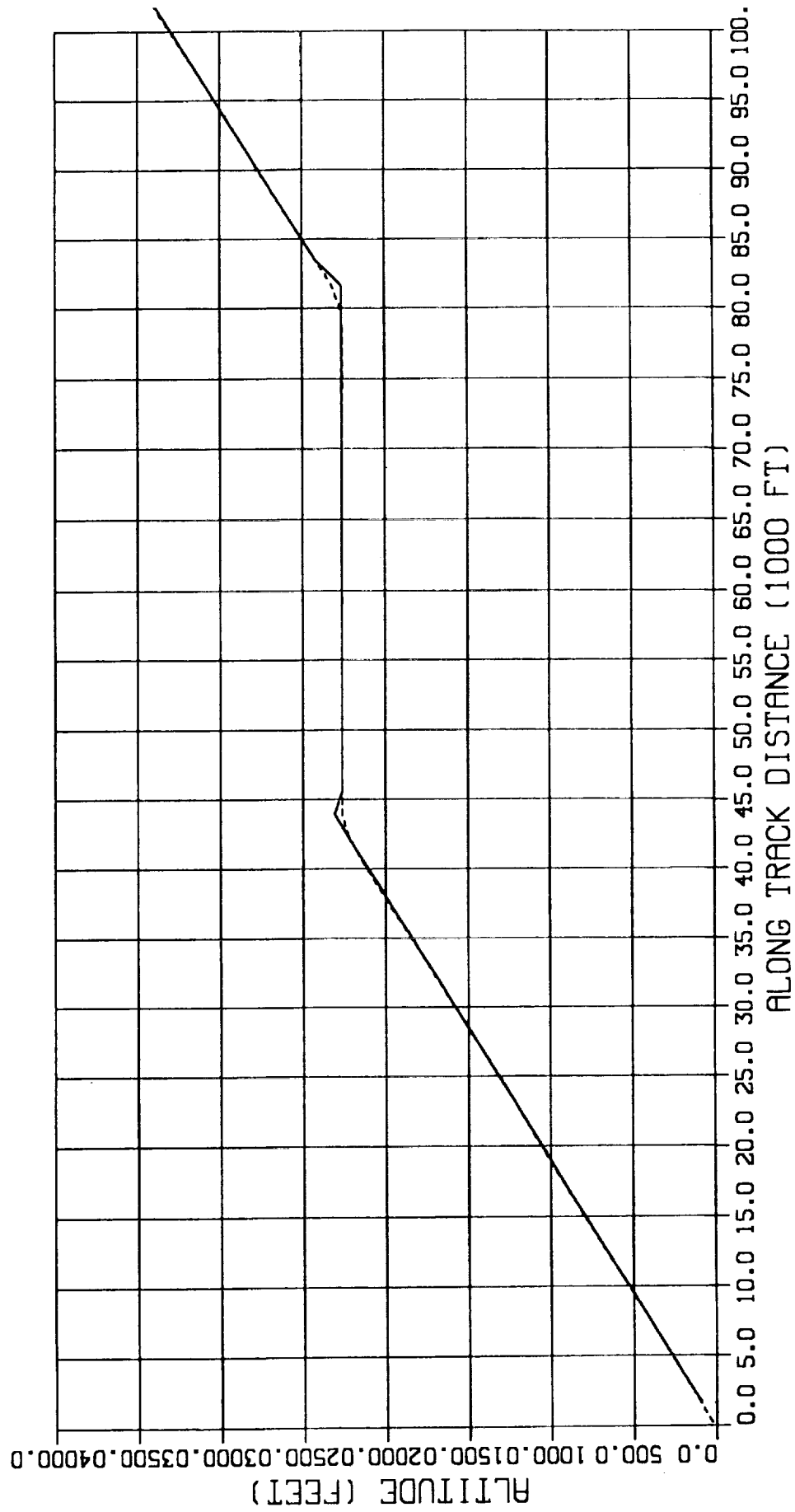


FIGURE 19. VERTICAL PROFILE FOR EWR 11

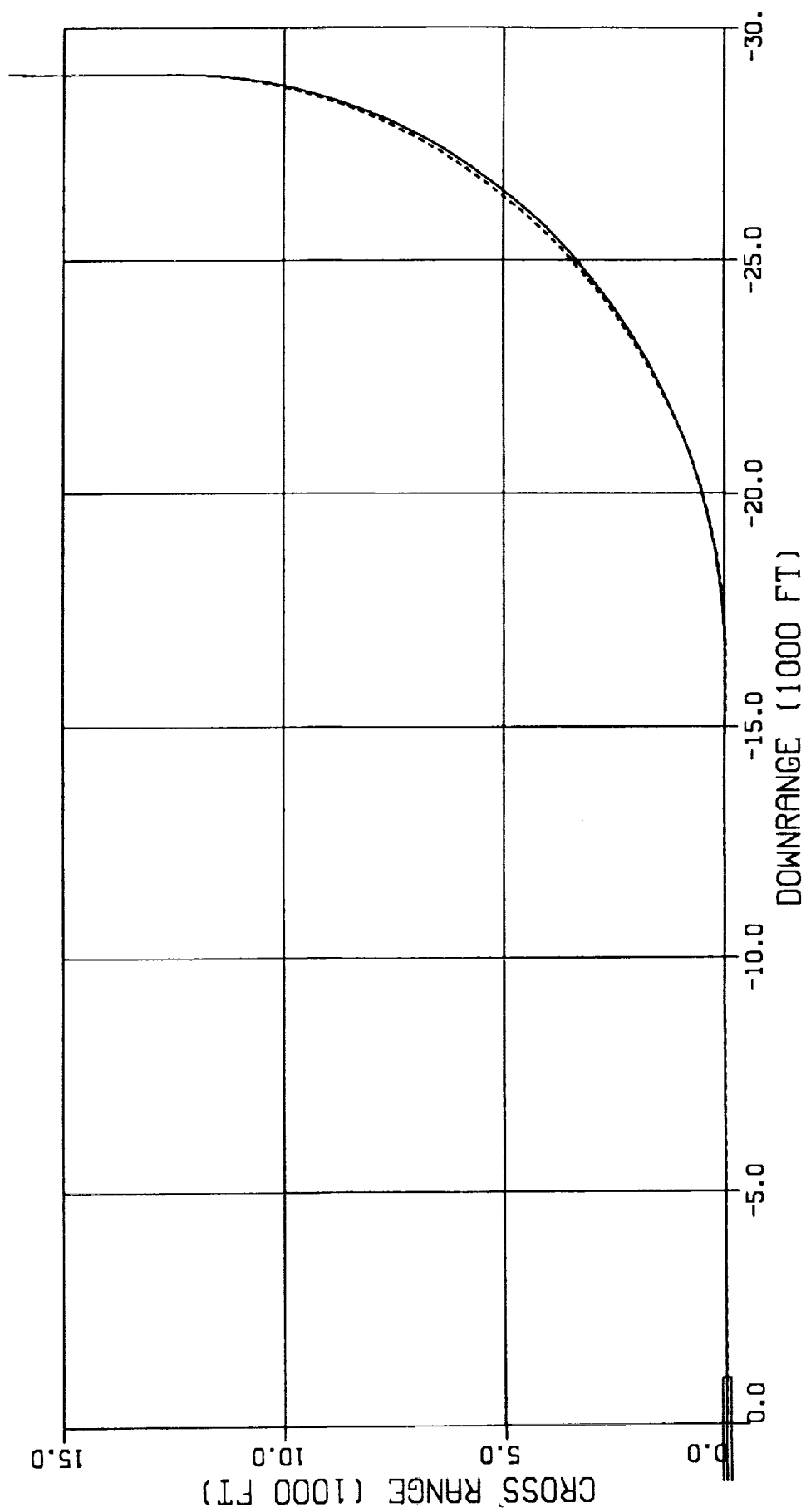


FIGURE 20. GROUND TRACK FOR LGA 13

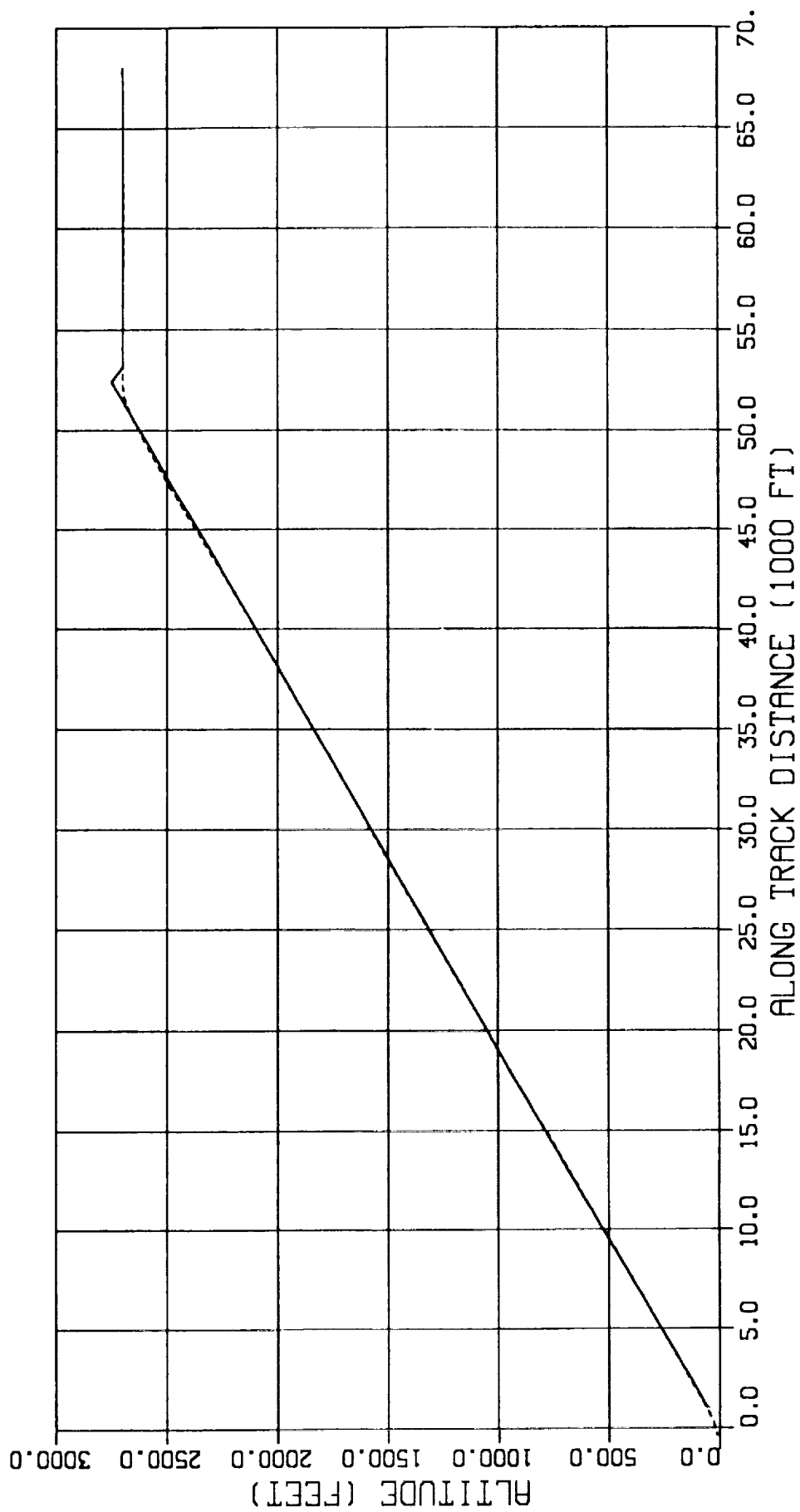


FIGURE 21. VERTICAL PROFILE FOR LGA 13

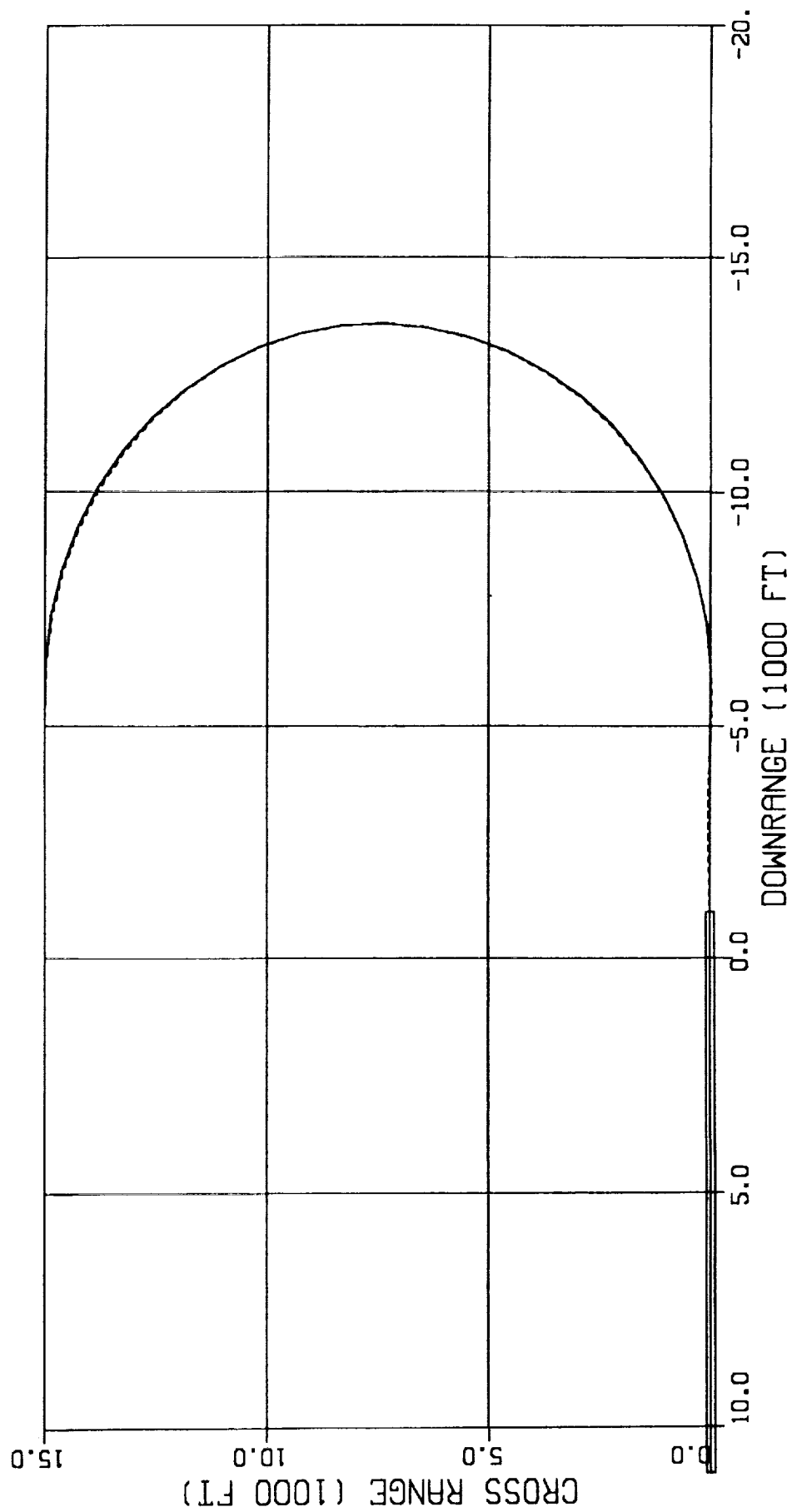


FIGURE 22. GROUND TRACK FOR 1-MILE TROMBONE



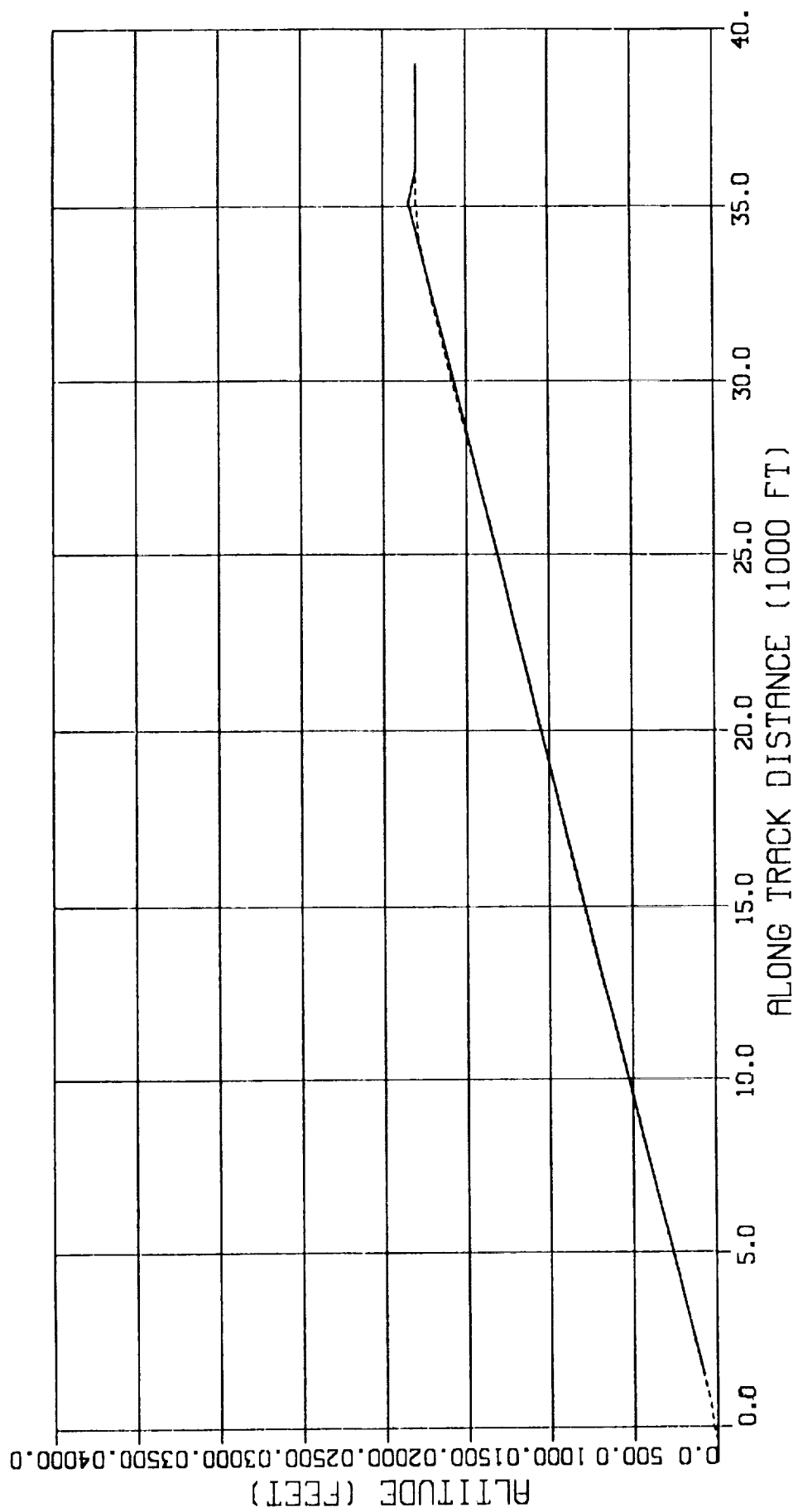


FIGURE 23. VERTICAL PROFILE FOR 1-MILE TROMBONE

as well as determine the structural limitations for the study aircraft configuration (WT = 132,000 lbs, Flaps = 40°, VE = 140 kts, CG = 25%).

The DCA River approach, with a 15 kt left crosswind was determined to have the greatest lateral velocity at touchdown of 8.2 ft/s. The 2 mile trombone with a 15 kt right crosswind proved to have the highest sink rate (vertical velocity) at touchdown of 4.1 ft/s. As a result, analysis was performed on both approaches to establish the structural limitations.

The current MD-80 main landing gear lateral load limits are calculated for two test conditions; a right turn, and a lateral drift, where the lateral drift case is considered most applicable to the touchdown performance experienced in this study. These tests produced the following data for two maximum landing weight (MLW) aircraft:

**MD-81 (MLW = 130,000 lbs)**

	<b>Right Turn Test</b>	<b>Lateral Drift Test</b>
MAXIMUM LATERAL LOAD (lbs) (perpendicular to tires)	51,487	25,156
MAXIMUM VERTICAL LOAD (lbs) (normal to tires)	102,973	41,926

**MD-83 (MLW – 150,000 lbs)**

	<b>Right Turn Test</b>	<b>Lateral Drift Test</b>
MAXIMUM LATERAL LOAD (lbs) (perpendicular to tires)	58,462	33,102
MAXIMUM VERTICAL LOAD (lbs) (normal to tires)	116,925	55,170

Once these structural limitations were determined, analysis performed on the simulated DCA River approach with a 15 kt left crosswind (with the worst lateral velocity at touchdown), as well as for the 2 mile trombone with a 15 kt right crosswind (with the worst vertical velocity at touchdown) produced the following results:

	<b>DCA River Approach 15kt Left X-Wind</b>	<b>2 Mile Trombone 15kt Right X-Wind</b>
MAXIMUM LATERAL LOAD (lbs)	12,726	5,714
MAXIMUM VERTICAL LOAD (lbs)	26,899	26,866

This analysis indicates that even the worst case touchdown performance experienced in this study does not compromise, nor exceed the aircraft main landing gear structural limitations for either the MD-81 or MD-83, and therefore is not considered to be a factor in categorizing the success of any study approach attempted.

It should be understood, however that this conclusion does not address every factor which can cause an approach to be unsatisfactory. For instance, during autoland certification, AC 120.28C requires that it be described "whether or not the aircraft landed within the desired touchdown dispersion area with lateral velocity or crosstrack error which could be corrected by the pilot or automatic system so as to remain within the lateral confines of the runway without a requirement for unusual skills or techniques." With no pilots in the loop, and without precise measurements of rollout performance, it is not possible to accurately predict the equivalent performance of the actual aircraft, based on the simulation results.

#### **6.4 PROCEDURAL CONSTRAINTS**

Once it was established that the lateral and longitudinal touchdown, as well as main gear structural limitations were not exceeded, the remaining criteria warranting consideration involved procedures, and the constraints they impose on each approach.

In order to complete an autoland approach, localizer and glide slope tracking logic, valid sensor inputs, as well as parallel rudder engagement must be satisfied no lower than 300 ft AGL with the present day MD-80 DFGC. For those approaches not satisfying this requirement, fail-passive autoland capability is inhibited, forcing the flight crew to take actions necessary to meet higher approach minimums (CAT II or less). The DCA River approach demonstrated the worst lateral velocity at touchdown. This poor performance can be directly attributed to the fact that localizer tracking logic is not satisfied by 300 ft, inhibiting the autoland align mode. In comparison, those approaches in which localizer tracking logic is satisfied above 300 ft demonstrated significantly lower lateral velocities with a worst case of 3.7 ft/s. As a result, an excessive error in tracking the localizer leads to poor performance once the aircraft approaches the runway environment.

#### **6.5 FLIGHT OPERATIONS REVIEW**

Upon review of the simulation results, two MD-80 engineering pilots were consulted in order to assess the MD-80 performance in MLS curved path approaches. Upon initial review, both pilots felt that the only acceptable approach was that of the ILS look alike which featured LOC/GS TRK well above 1,500 ft (approximately 2,200 ft). The following comments were made:

1. Glide slope capture should occur at approximately 1,500 ft, or at final approach fix (FAF).
2. LOC/GS TRK should occur no lower than approximately 1,500 ft.
3. Aircraft should be stabilized (on speed, flaps in landing configuration, gear down, on GS/LOC) no lower than 1,000 ft.
4. Autoland criteria should be met by 1,000 ft, preferably 1,500 ft.
5. Align mode must occur at 150 ft.
6. Flare mode must occur at approximately 50 ft.

Further review of the remaining approaches identified numerous constraints, not only of the aircraft, but also for the defined approach procedure. For instance, for all approaches, with exception to that of the ILS look alike, turns to the final straight segment of the approach occur well below the normal 1,500 ft altitude. Therefore, in utilizing MLS guidance to place the aircraft in a position to capture and track the ILS, the approach plate dictates that the GS/LOC TRK will occur at a posi-

tion much lower than required to stabilize the aircraft prior to landing. Both pilots strongly felt that the flight crew, as a result of these lower than normal ILS intercept altitudes would not have sufficient confidence in the aircraft position relative to the localizer beam, speed, and rate of descent.

Several approaches reviewed achieved LOC/GS TRK at altitudes well below 1,000 ft. Current DGFC control laws inhibit autoland by disengaging the autopilot in the event autoland criteria (LOC/GS TRK, parallel rudder engaged, and all required sensors valid) is not satisfied by 300 ft. In the event autoland criteria is met at or shortly before reaching 300 ft, pilot feedback indicated that the time interval between 300 ft to 200 ft to 100 ft is narrow enough to cause confusion in determining which weather minimums apply; 200 ft DH for CAT I, 100 ft DH for CAT II, or 50 ft DH for CAT IIIA fail passive autoland. This theory further supports the requirement for autoland engagement no lower than approximately 1,500 ft during the approach.

In addition to the aforementioned constraints identified, several other factors were identified which would make a successful approach using MLS guidance as defined in this study less likely. For those aircraft not equipped with windshear detection equipment, windshear detection is extremely difficult during speed transitions, as might be experienced during curved path approaches. Speed, and rate of descent stabilization must be established in order to allow the detection of decreasing, as well as increasing performance windshears. Therefore, until the aircraft is stabilized on the ILS in a landing configuration, it is vulnerable to the effects of a windshear.

Aircraft display systems were also identified as a limitation for any curved path approach attempted. Aircraft without EFIS navigational displays, as is the case for the majority of the existing DC-9 series aircraft, would be at a distinct disadvantage. Prior to achieving LOC/GS TRK, with the aircraft in a stabilized configuration, pilots consulted stated that the flight crew would not have a displayed position accurate enough to have confidence in completing the approach. In addition, even the most advanced MD-80 cockpit, such as that found on the current MD-88 aircraft, is thought to provide inadequate guidance/position information for a curved path approach as defined in this study. The current MD-88 is equipped with EFIS primary and navigational displays, incorporating an FMS system capable of depicting the airport/runway position, as well as a curved path within the terminal area with an accuracy of 1.5 n mi. Pilot feedback indicated that this position accuracy is questionable in providing the precision required for MLS curved path approaches.

MLS equipment installations were also addressed in order to stress the factors pertinent to safe flight operations. The current proposed MLS installation would include not only MLS receivers and control panels. In addition to these items, appropriate MLS annunciations would also be required on the FMA and other possible locations which would leave no doubt in the minds of the flight crew as to which mode they had selected, and which mode they were presently in. Paramount to this proposed design would be a clear and effective means of annunciating the transition from MLS guidance to ILS guidance, for a system architecture similar to that as simulated in this study.

Upon final review, the following suggestions, comments were made:

1. Modify existing DFGC control laws in order to achieve localizer capture significantly earlier than experienced in the simulation; preferably above 1,500 ft AGL.

2. Modify existing approach procedures to accommodate current MD-80 aircraft operations. These modifications might include larger radius turns requiring smaller bank angles, as well as final turn completion prior to 1,000-1,500 ft when applicable.
3. Modify existing flight deck avionics in order to instill confidence in the MLS equipment, procedures, and capabilities. The principle areas requiring modification are flight mode annunciation and ergonomically designed positional display information.



## **SECTION 7 SYSTEM MODIFICATIONS**

To realize the full potential of MLS, modifications in the areas of both procedure and autopilot (DFGC) control laws are required.

### **7.1 MLS PROCEDURE CHANGES**

#### **7.1.1 Curved Path Definition**

There are several modifications that could be made to allow more MLS curved path approaches to be successful. The MLS curved approach paths could be designed to have somewhat longer final segments with a larger turn radius. In general, the MLS paths should be such that they take advantage of MLS capabilities, and at the same time are compatible with successful autolands.

#### **7.1.2 Crew Procedures**

In order to perform curved path approaches which transition to an autoland with the existing MD-80 avionics, flight crew training procedures need to be modified. This task might include the development of procedures which enable the recognition of aircraft position relative to the curved path, as well as the runway environment. In addition, a correlation between current ILS procedures and MLS curved path procedures should be clearly identified in order to produce a usable approach procedure routine. This routine would establish significant milestones/checkpoints throughout the curved path procedure equivalent to that experienced with ILS operations, such as final approach fixes, outer markers, inner markers, as well as appropriate altitudes, airspeed, aircraft configuration, and checklist completion relative to a unique position fix.

### **7.2 DFGC CONTROL LAW**

The following criteria for localizer capture and tracking currently exists in the DFGC:

#### **7.2.1 Localizer Capture**

Localizer capture is initiated when one of the two following conditions are met:

- The product of localizer lateral deviation with that of the sum of the damping roll command and roll error command is less than zero.

OR

- The absolute value of the localizer deviation rate is less than 25 ft/sec and the absolute value of the localizer lateral deviation is less than 500 ft.

In simple terms, the aircraft is close enough to the localizer beam with an appropriate beam deviation rate to provide a smooth capture with minimum overshoot. Capture will be initiated immediately if the pilot selects an ILS (autoland) mode when the aircraft is already situated and stabilized near the localizer beam center.

#### **7.2.2 Localizer Tracking**

Localizer tracking is engaged when the following conditions are met:

- The absolute value of the total roll command, and measured roll attitude is less than  $3^\circ$  (the aircraft is essentially wings level), and the absolute value of the localizer lateral deviation is less than 240 ft (on beam center), and the absolute value of the localizer deviation rate is less than 12 ft/sec (beam deviation rate is small).
- The engagement of localizer tracking is inhibited until 10 seconds have elapsed following localizer capture initiation.

### 7.2.3 Control Law Changes

The aircraft is guided laterally by the MLS steering signal during the curved path segments. This signal is generated by a simulation subroutine which is external to the simulated autopilot routines. Upon turn to final, the MD-80 simulated autopilot localizer capture mode is automatically armed and as the criteria for capture are met, the system switches modes for the final guided segment. Arming could begin while the aircraft is still in the last turn; however, the localizer deviation is measured from the extended runway centerline and will be large until the aircraft is lined up on final. A change to the DFGC could be made to use the deviation from the curved path during the capture mode, thereby allowing earlier tracking. Modifications to the inner loops (refer to Figure 2(B)) may be necessary to implement this concept, unless simple switching could be employed inside the MLS guidance computer. Follow-on studies are needed to verify this concept.



## SECTION 8 EXISTING AIRCRAFT APPLICATIONS

### 8.1 MLS INSTALLATIONS

To date, no production MLS installation has been incorporated on any of the early DC-9 series aircraft. An MLS retrofit installation however has been proposed for the DC-9 series 80 (MD-80) aircraft. This retrofit consists of a dual independent ARINC 727 MLS designed for straight in (ILS look alike) CAT IIIA approaches and autoland. Conceptually, this installation is intended for the minimum change possible with no modification to the MD-80 autopilot, electronic flight instrumentation system, or any other existing system. The following describes equipment and the installation necessary to realize this capability:

- Two 3MCU ARINC 727 Canadian Marconi CMA-2000 MLS receivers are to be located in the radio rack. The receivers will be qualified to TS0-C104. The CMA 2000 software is designed using the guidelines of RTCA DO-178A level 1. The autoland function is classified as critical per FAR 25 section 1309.
- Two MLS control panels are to be located, one on each side of the forward pedestal. The control panel will be qualified to TS0-C104 (See Figure 24).
- One Butler National Switching Unit is to be used to provide switching between MLS and ILS receivers. (See Figure 25). This unit will be located in the radio rack. The MLS/ILS switching unit is controlled via two push/push type lighted switches, one located on each pilot's instrument panel, near the FMA (flight mode annunciator). (See Figures 26 and 27.) This switching unit is available since it has been designed for and previously certified to provide autoland wire separation.
- Five C-Band MLS antennas will be installed in accordance with ARINC 727 (See Figure 28).  
  
Two blade type antennas for MLS 1 and 2 would be installed on top of the fuselage side by side, at about station 205. These antennas would be utilized for the approach phase, and possibly also for rollout guidance, if selected by the customer.  
  
Two additional antennas (MLS 1 and 2) of the same type will be mounted within the nose radome, collocated with the present-day glide slope antenna. These antennas will be utilized for final approach segment, landing, as well as rollout phase guidance.  
  
Finally, a single Canadian Marconi antenna with integral amplifier will be installed on the lower aft fuselage to provide downwind, and missed approach (back azimuth) guidance.
- This proposed MLS architecture includes the use of existing flight instrument displays, as currently used for ILS operations. MLS channel and angular information, as well as fault conditions, will be provided in the MLS controls.

It is important to note that this retrofit does not include the software/hardware changes required to annunciate MLS modes on the FMA. As a result, the ILS equivalent mode will be annunciated. For example, MLS azimuth capture will be annunciated as LOC CAP (Localizer Capture). Extensive software and hardware changes required to annunciate the proper MLS modes have been considered too costly for the purpose of a retrofit program, and subsequently are not included in the proposed design architecture.

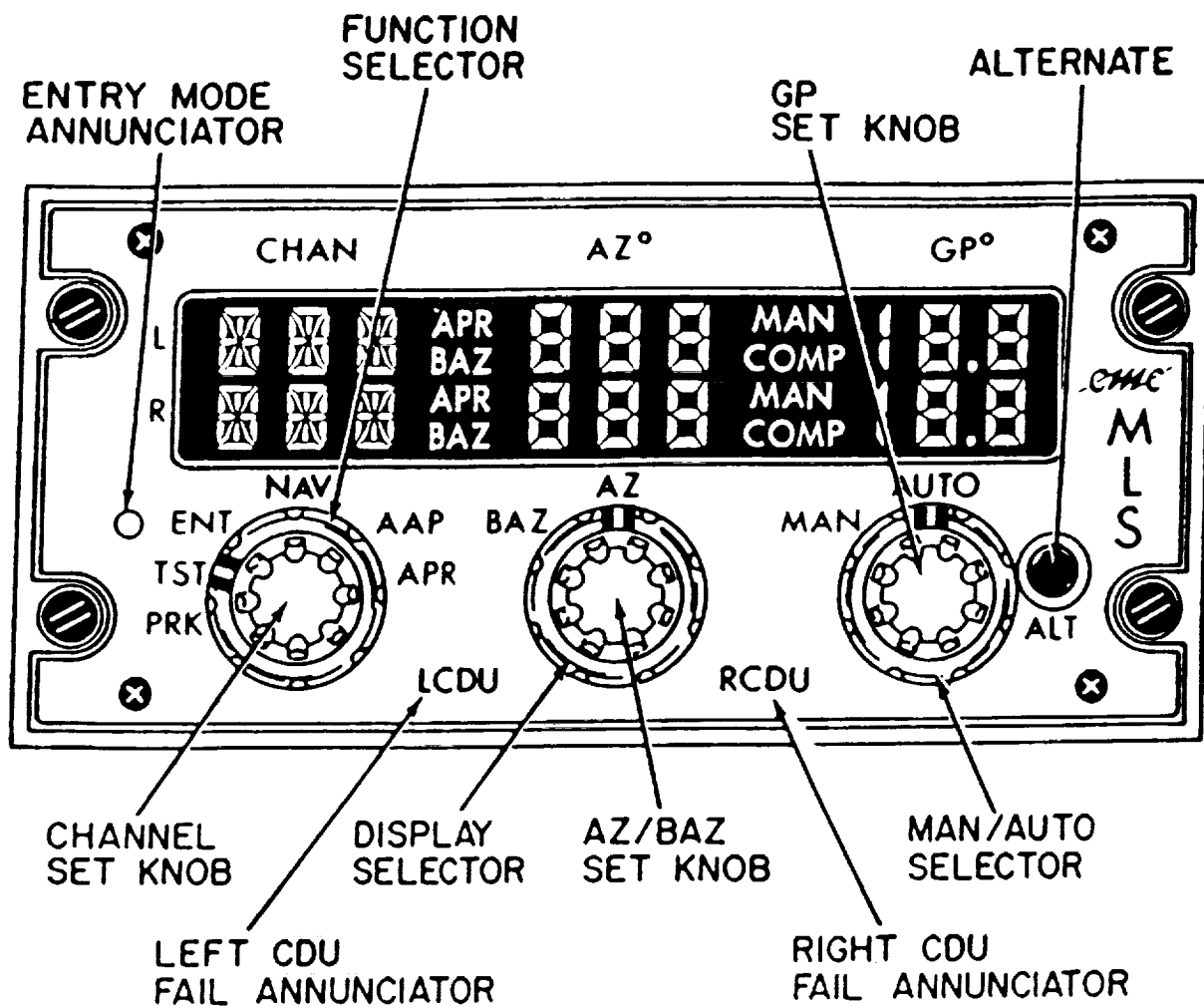


FIGURE 24. CANADIAN MARCONI MLS CONTROL PANEL

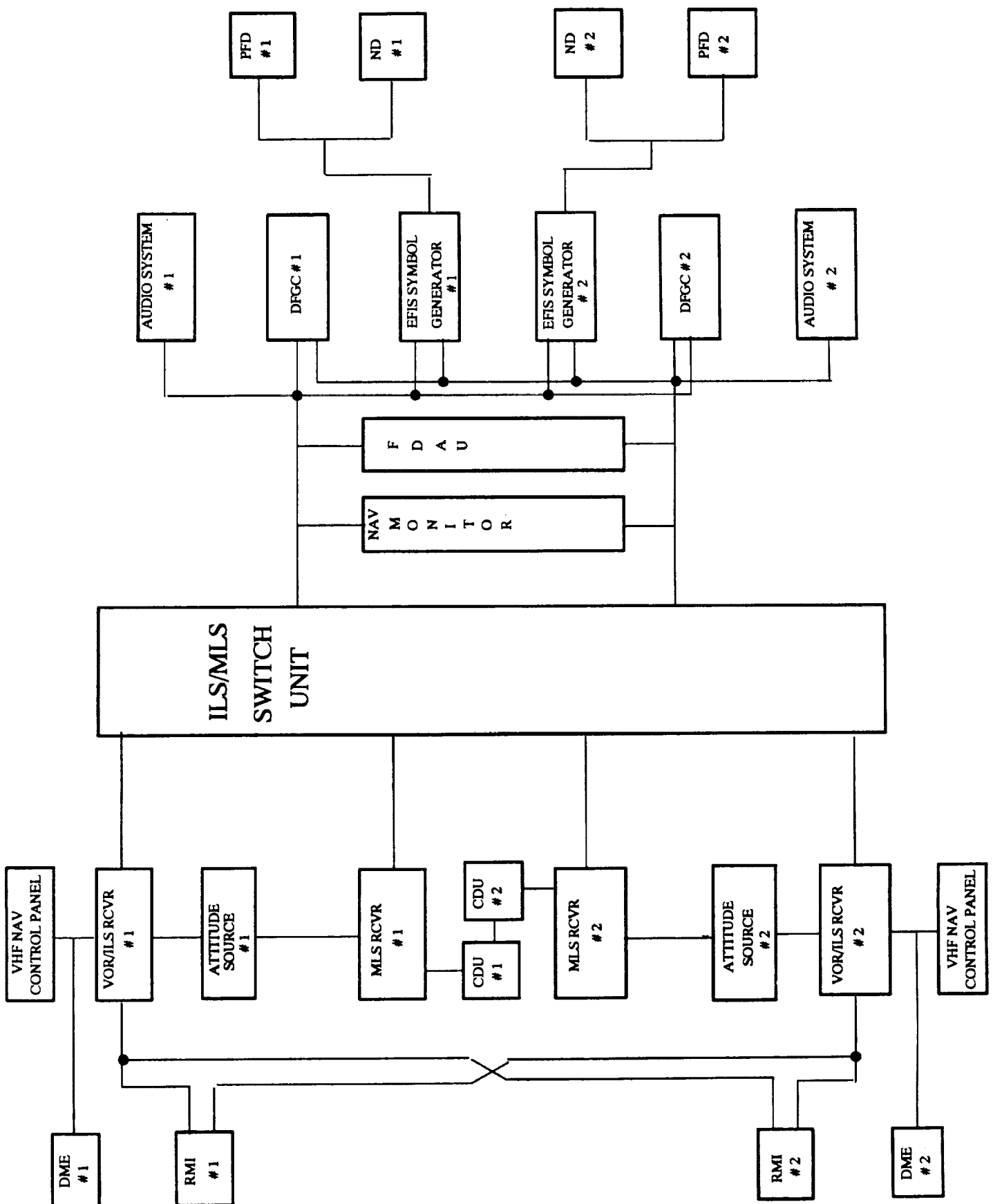
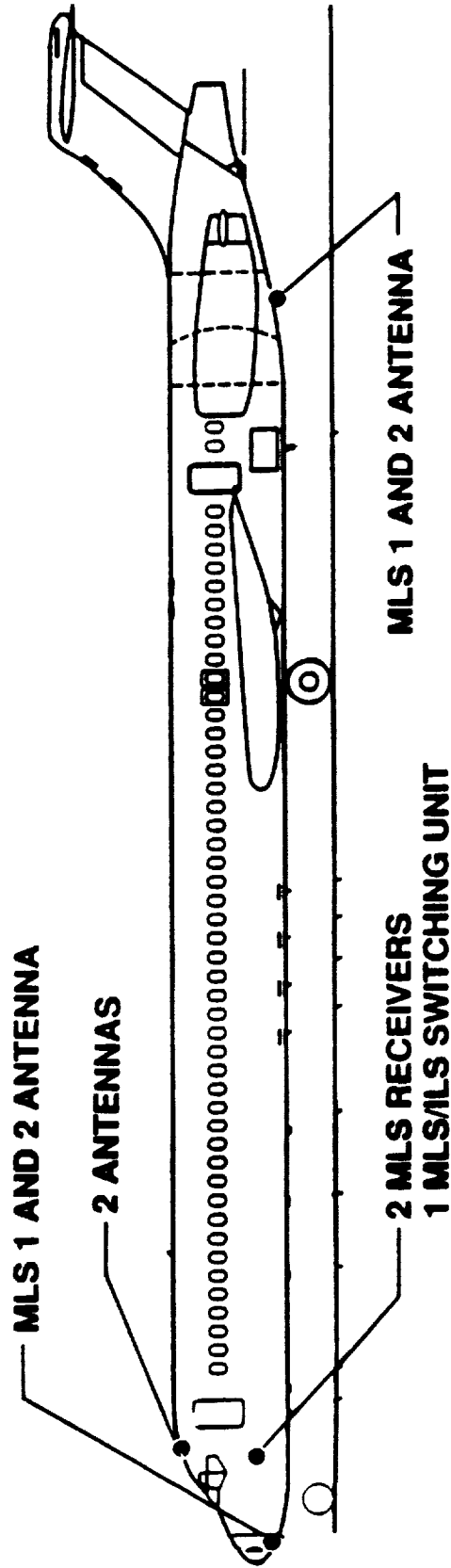


FIGURE 25. MLS/ILS SWITCHING ARCHITECTURE BLOCK DIAGRAM







- INSTALL TWO ARINC 727 MLS RECEIVERS IN RADIO RACK
- INSTALL TWO ANTENNAS ON THE TOP OF FUSELAGE AT STATION 205
- INSTALL TWO ANTENNAS INSIDE NOSE RADOME
- INSTALL ONE ANTENNA WITH INTEGRAL AMPLIFIER ON LOWER FUSELAGE AT REAR OF ACFT
- INSTALL TWO MLS CONTROL DISPLAY UNITS IN THE FORWARD PEDESTAL
- INSTALL ONE MLS/ILS SWITCHING UNIT IN RADIO RACK
- INSTALL A LIGHTED SWITCH INDICATOR (GREEN, MARKED MLS) CLOSE TO THE FLIGHT MODE ANNUNCIATOR

FIGURE 28. PROPOSED MLS ANTENNA INSTALLATIONS

## 8.2 FMS APPLICATIONS

The MD-80 Flight Management System provides vertical, as well as lateral navigational guidance, navigation display, and aircraft performance optimization for all flight regimes. The FMS is currently certified for both MD-80, as well as MD-87 aircraft.

As an alternative to MLS, the FMS might be utilized to provide an extensive nav data base capable of storing waypoints sufficient to define an MLS curved path and/or segmented glide slope approach. Vertical (VNAV) and lateral (NAV) navigation guidance is currently approved for non-precision RNAV approaches with the following restrictions:

1. The FAA requires that VNAV and NAV guidance must be disengaged below 1,000 ft AGL for aircraft equipped with vertical gyros (VG), directional gyros (DG), or an Attitude Heading Reference System (AHRS).
2. The FAA currently requires that VNAV and NAV guidance must be disengaged below 400 ft AGL for aircraft equipped with an Inertial Reference System (IRS).

### 8.2.1 General Specifications of the Current MD-80 FMS

Provided usable signals are being received from at least two DME stations, or one VOR/DME station, the MD-80 FMS has been demonstrated to meet the requirements for VFR/IFR RNAV operation of AC 90-45A:

	Cross Track Accuracy (n mi)	Along Track Accuracy (n mi)
Enroute	2.5	1.5
Terminal	1.5	1.1
Approach	0.6	0.3

Cross track is defined as the distance in nautical miles between the actual aircraft position and the desired aircraft position, measured at right angles to the desired path.

### 8.2.2 Waypoint Loading/Capacity

FMS approach and approach transition procedures are coded per ARINC Specification 424 and emulate current Jeppesen charts. Each approach is defined by a unique procedure code.

### 8.2.3 FMS Guidance

During an approach, FMS guidance is automatically disengaged upon localizer or VOR capture by the DFGC. Typical intercept angles of 30-45° are utilized during the approach transition. The FMS provides guidance to ensure localizer capture when the following conditions are met:

1. The approach is a data base defined ILS, backcourse, or LOC procedure, or a manually constructed approach to a localizer equipped runway which places the aircraft course within  $\pm 5^\circ$  of the localizer beam centerline.
2. The active approach transition leg must intercept the localizer waypoint within 14.2 n mi.

3. The autopilot or flight director LOC mode must be armed.
4. The appropriate localizer/ILS frequency must be selected.
5. All FMS equipped aircraft are required to have a DFGC option which prevents glide slope capture prior to localizer capture.

#### **8.2.4 FMS Assessment**

The current FMS guidance for curved and/or segmented approaches is limited due to the navigational accuracy required to perform precision maneuvers close to the ground, as depicted in the study approach plates. The FMS data base does however provide sufficient capacity to store numerous complex approach procedures. This is of great significance in that not all on-board MLS equipment possess this capability. Once an MLS procedure is depicted on a Jeppesen chart, this information can be easily loaded, changed, and updated providing immediate access to the flight crew. (See Figure 29.)

Upon review of the constraints governing the operation of FMS on the MD-80 series aircraft, current FMS is capable of performing the approach transition to 1,000 ft (400 ft for IRS aircraft). As a result, for VG/DG and AHRS equipped aircraft, only the ILS look alike approach would be practical with a localizer capture occurring well above the aforementioned altitude constraint. It is theoretically possible however for an IRS equipped aircraft to perform additional approaches (JFK 13R, EWR 11, LGA 13, 2 and 3 mile trombone) as these approaches feature final turns prior to localizer intercept above 400 ft AGL. Further simulation analysis would be required in order to further evaluate this scenario as it is unknown how the FMS-DFGS transition would affect results.

### **8.3 OMEGA APPLICATIONS**

The Canadian Marconi CMA-771A and Litton LTN-211 Omega/VLF navigation systems are certified for use on all MD-80 aircraft. These systems provide en route lateral guidance, as well as navigation display on either an electromechanical HSI, or on an EFIS Navigational Display (CMA-771A version -313 only). The Canadian Marconi CMA-771A is the more advanced Omega, capable of storing a data base of 1800 different waypoints, and a total 4000 waypoints.

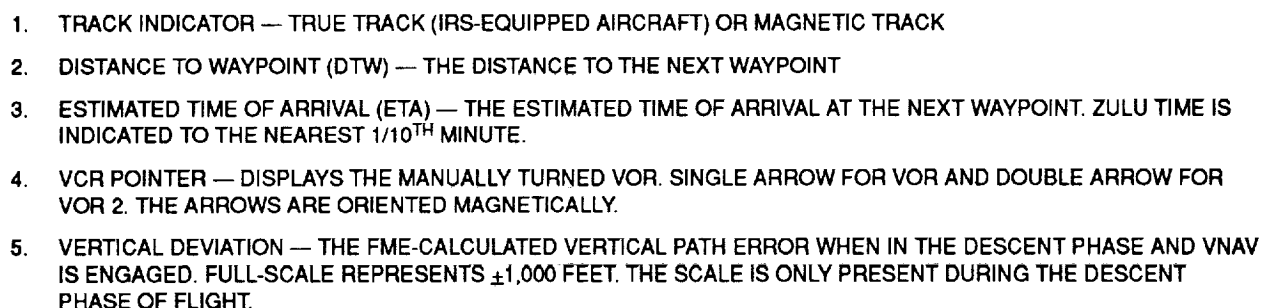
The Omega meets en route accuracy requirements of  $\pm 2.8$  n mi cross track and  $\pm 2.8$  n mi along track, per AC 20-101C and 2.5 NM cross track and 1.5 n mi along track, as dictated by AC 90-45A.

Omega, however is not approved by the FAA for terminal area navigation, neither during approaches nor departures. In addition, Omega should not be used when flying into valleys between peaks in mountainous terrain or below minimum en route altitudes (MEA). Finally, Omega does not provide vertical guidance which is required to conduct segmented, as well as constant glide slope curved path approaches. As a result, the current Omega systems certified for use on the MD-80 are not capable of performing curved path approaches.

### **8.4 INS APPLICATIONS**

Inertial Navigational Systems (INS) are not currently certified for commercial use on the DC-9 series aircraft. The only certified configuration was installed on the DC-9-30F, a military version of the DC-9 series 30 aircraft. This system, when coupled with the DC-9 analog roll computer, provided en route lateral navigational guidance with an accuracy of approximately 1 n mi/HR, with a groundspeed error less than or equal to 8 kts.





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The INS does not have the capability to provide vertical guidance and is therefore not capable of performing segmented, as well as constant glide slope MLS curved path approaches.

## **8.5 GPS APPLICATIONS**

The Global Positioning System (GPS) is a high-accuracy, satellite based, navigation system. The satellite constellation is to consist of 21 satellites, with 3 spares. In using this constellation, GPS will provide 24 hour, worldwide signal coverage for computations of time, position, velocity, and acceleration in a 3-dimensional format.

The commercial industry will use receivers that can acquire the course acquisition (C/A) code, providing accuracy of approximately:

Position . . . 40 meters

Velocity . . . 0.1 meters/sec

Time . . . . . 350 nsec

GPS is not currently certified for use on the MD-80 aircraft. GPS is expected to be phased in to the commercial industry as experience with the system is obtained. It is anticipated that GPS will be used initially as an accurate enroute position-fixing system. As confidence in its capabilities grows, GPS may be utilized in terminal areas and in some approach modes.

## **8.6 DC-9 APPLICATIONS**

Several earlier DC-9 aircraft configurations feature an Automatic Flight Control System (AFCS) and are certified to perform a CAT II approach (100 ft DH, 1200 ft RVR). The AFCS enables intercepting and tracking of an ILS localizer and glide slope down to approach minimums. The DC-9 differs with that of the DC-9 series 80 aircraft in that it does not have the capability to perform a CAT IIIA autoland. As a result, the DC-9 AFCS does not have the ability to provide align, flare, and rollout guidance.

Initial investigations indicate that MLS steering commands could be directed to the existing DC-9 AFCS. However, no simulation, nor actual flight test data exists to support this statement. Nonetheless, it is theoretically possible to perform an ILS look alike approach utilizing the existing AFCS control laws, and hardware when integrated with an MLS.

A curved path approach however poses additional problems. No extensive NAV data base is currently certified, nor available for use on the earlier DC-9 series aircraft. As a result, a separate NAV data base would have to be developed and certified for integration with the DC-9 analog AFCS. This navigational capability would be required in order to place the aircraft in a position to capture the ILS, following any curved path maneuver.

In addition, the DC-9 AFCS has constraints which might prevent successful localizer captures as attempted in this study. The following limitations might contribute to this problem:

- Maximum roll rate . . . . . 4°/sec  
(During Loc Cap)

- Maximum roll rate . . . . . 4°/sec  
(During Loc Trk)
- Maximum bank angle . . . 25°  
(During Loc Cap)
- Maximum bank angle . . . 9°  
(During Loc Trk)

## 8.7 MD-80 OPTIMUM AVIONICS CONFIGURATION

The optimum avionics configuration currently available is flown by Iberia Airlines (MD-87), as well as by Polaris (MD-88) consisting of dual FMS, IRS, and EFIS primary flight, and navigation displays. This avionics configuration offers the best "springboard" to attaining an aircraft configuration capable of performing MLS curved path approaches.

With the incorporation of IRS and FMS, vertical and lateral FMS guidance currently is allowed down to 400 ft. In addition, the integration of FMS and EFIS displays allows depiction of pertinent navigational information used for the approach segment on the Navigation Display (ND). Basic attitude, as well as course deviation can be displayed on the Primary Flight Display (PFD).

In addition to enabling lower FMS minimums, IRS may be utilized to provide additional information such as ground speed, wind speed, wind direction, as well as acceleration. However, this design architecture is not currently available on the MD-80 aircraft as no serial data bus exists between the DFGC and the Inertial Reference Unit (IRU). Regardless of how the MLS is integrated into the aircraft, this configuration represents the closest to optimum baseline MD-80 aircraft for MLS curved path procedures.

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# REPORT DOCUMENTATION PAGE

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